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WATER POLLUTION CONTROL BENEFITS AND COSTS. VOLUME II. RESEARCH NEEDS AND PRIORITIES

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Development Planning and Research Associates, Incorporated
Manhattan, Kansas

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October 1973

RESEARCH NEEDS AND PRIORITIES: WATER POLLUTION CONTROL BENEFITS AND COSTS

VOLUME II

by

David L. Jordening
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Contract No. 68-01-0744
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ABSTRACT

This report includes foremost a specification of research needs and priorities involving water pollution control costs and benefits. A series of theoretical and methodological research needs are presented. Water quality management is required in a dynamic setting and over a broad range of hydrologic and economic conditions. The common property resource aspects of the problem with the prevalence of externalities complicates the issues involved. These and other factors embedded in the research needs are discussed.

A major development of a cost-minimization methodological approach for water quality management is also presented. Within this framework the indicated research needs are more readily identified and explained.

An important distinction is made between the economic costs of pollution and the costs of pollution abatement. The economic costs of pollution such as damages, efficiency reductions, increased production expenses, process changes and opportunity costs are a function of water quality, whereas pollution abatement costs are typically a function of the degree of pollution control. For comparable cost comparisons, a transformation of pollution abatement costs in terms of water quality is desired. This transformation need and problem is discussed in detail.

Finally, in a series of technical appendicies, the following subjects are discussed:

(1) water pollution control cost and benefit estimates,
(2) water quality associated health impacts,
(3) specific pollutant sources, damages and potential treatment methods, and
(4) critical levels and damage threshholds for selected pollutants.

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CONTENTS

Page

Abstract ii

Exhibits iv

Acknowledgments vi

Executive Summary vii

Sections

I Background Perspectives and Research Needs 1

II A General Methodological Approach 30

III Economic Cost of Pollution 63

IV Cost of Pollution Abatement 78

V Estimating Water Quality as a Function of Pollution Control 83

VI Conclusions and Direction of Future Work 119

VII Appendices 125

EXHIBITS

No.		Page
II-1	Benefits of pollution abatement measures in the Ohio River Valley in the various uses of the surface water	37
II-2	Annual costs and benefits of water pollution abatement measures	38
II-3	Effect of degree of removal of dissolved organic matter from effluents on annual costs and economic benefits due to pollution abatement in the Maumee River Basin	40
II-4	Treatment processes that can be costed by the wastewater treatment plant cost estimating program	44
II-5	Cost of treatment and degree of control (by treatment strategy)	45
II-6	Water quality and percent treatment	48
II-7	Economic costs of pollution	50
II-8	Total water quality benefits	52
II-9	Total cost of waste disposal	60
III-1	Beneficial use classifications and specific impacts of water pollution	65
III-2	Economic costs of pollution	68
III-3	Economic cost of pollution in reference to municipal preuse treatment	72
III-4	Recreation participation variables	74
IV-1	Total capital, operating and maintenance costs required to meet current standards in 1968 and 1976	81
V-1	Effect of degree of removal of dissolved organic matter from effluents on annual costs and economic benefits due to pollution abatement in the Maumee River Basin	84

EXHIBITS (continued

No.		Page
V-2	Selected water quality characteristics	87
V-3	Drinking water standards of the U.S. Public Health Service, 1962	88
V-4	Classification of water quality according to hardness and salinity properties	90
V-5	Assessment of surface water quality by a single index of pollution	91
V-6	Battelle's Environmental Evaluation System	92
V-7	Components of the PDI water quality measurement system	97
V-8	Total assimilative capacity of streams of different orders	99
V-9	Sources of surface water pollutants	100
V-10	Variations in dissolved solids and sediment concentrations in major river basins in arid and semiarid United States	103
V-11	Water quality characteristics adopted for this study	107
V-12	General form of surface water quality - degree of control curves	109
V-13	Raw and treated effluent flows, illustrative case	112
V-14	Surface water quality as a function of effluent load, BOD by quarter of year, illustrative example	115
V-15	BOD content of treated effluent as a function of degree of treatment, illustrative case	116

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EXECUTIVE SUMMARY

The principal objective of this report is to specify research needs and priorities involving water pollution control costs and benefits. In addition, a major extension toward development of a cost-minimization methodological approach for water quality management is presented.

Research needs and priorities are based both on a state-of-the-art review and a critical evaluation of methodologies and approaches to water quality management which have been used. Further, the research needs and priorities can be formulated only when an adequate analytical framework and general technique has been selected. Such a framework, limited to partial equilibrium analysis techniques, is presented in Section II.

In summary, this report is divided into six sections.

I. Background Perspectives and Research Needs
II. A General Methodological Approach
III. Economic Cost of Pollution
IV. Cost of Pollution Abatement
V. Estimating Water Quality as a Function of Pollution Control
VI. Conclusions and Directions of Future Work

Section I reviews the state-of-art findings (Part I) plus additional partial equilibrium approaches. A critical evaluation of existing work is made and research needs and priorities are stated. Section II presents and recommends a partial equilibrium technique for future use. Sections III, IV and V are needed extensions arising from the methodological approach adopted in Section II. The final section presents general conclusions and outlines some specific areas of study which are proposed for further consideration by EPA. In addition, a series of appendices are included and referenced in the report.

I. Background Perspectives and Research Needs

There is evidence of considerable lack of direction and coordination in water quality management literature. In most cases it can be said that water quality management literature is at the infancy stage. There is also the failure on the part of many to recognize the common property resource aspects of water quality management which is the primary source of environmental quality problems. This inevitably leads to a symptomatic approach to the problem rather than a direct confrontation of the major factors involved in the water quality management problem.

Many of the partial equilibrium studies are either high project-problem-crisis oriented or consider only a very small portion of the total first round or primary impacts of water quality deterioration.

The approaches to the water quality management problem can be segmented into two broad categories based on the level at which they address the problem, i.e., general equilibrium as opposed to partial equilibrium analysis.

There is considerable controversy in the literature covering the proper theoretical approach to be utilized in assessing water quality associated impacts. Both the general equilibrium and partial equilibrium approaches have their own respective strengths and limitations. The quest for immediate answers and the many uncertainties associated with water quality management necessitates adopting a readily accessible pragmatic approach to the problem. In this regard partial equilibrium methods must be selected, duly recognizing the inherent limitations.

Methodological and Theoretical Research Needs

A series of general methodological and theoretical research needs are presented. Water quality management is required in a dynamic setting and over a broad range of hydrologic and economic conditions. The common property resource aspects of the problem with the prevalence of externalities complicates the issues involved. These and other factors are embedded in the general research needs.

Some general methodological and theoretical research needs (not listed in order of priority) include:

1. Development of methods and procedures to identify and quantify water associated benefit and cost functions relating specific benefits and costs to specific pollutants.

2. Development of economic and hydrologic models to identify and quantify complex intra- and interbasin relationships.

3. Extension and refinement of accounting measures, such as "insurance values," for uncertain water quality associated costs and benefits.

4. Formulation of a measure of value that can be used as a common denominator additive measure to effectively evaluate all intangible and indirect nonmonetary costs and benefits associated with changes in water quality.

5. Development of alternative pollution abatement policies designed to minimize undesirable equity and distribution impacts associated with water quality control.

6. Quantification of complex water quality substitution effects. As water quality deteriorates, certain substitution effects may be expected.

7. Development of an aggregation framework to assess regional and national pollution control costs and benefits.

8. Assessment of alternative political, legal and institutional arrangements needed to perform water pollution control management functions.

9. Development of procedures to project and evaluate alternative distributions of benefits and costs through time, i.e., "time profiles," including the use of a social discount rate to compute present value.

10. Estimation of net social benefits attributable to water pollution control measures, i.e., measurement of a social welfare function. Water pollution control measures are expected to impact economic structures with consequent relative shifts in supply and demand relationships. Such consequences call for analysis of the social welfare function.

The above list includes a variety of methodological and theoretical research needs, some of which suggest that a substantial reassessment of commonly held social objectives is in order.

Data Input Needs

The solution of water quality management problems cannot be satisfactorily pursued until a comprehensive understanding of natural and physical relationships has been achieved and quantified. The absence of such data input at the present time limits the accuracy of comprehensive national benefit and cost function that may be developed.

Some of the physical, chemical, biological, economic and engineering data input needs include, but are not limited to, the following items:

1. Relationships between waste treatment cost and effluent water quality for each pollutant and for each type of industrial and municipal wastes.
2. The quantity of each pollutant from non-point sources which enters each receptor.
3. The extent of assimilation of each pollutant by natural processes in each receptor.
4. The effect of each pollutant on municipal and industrial water treatment processing costs where surface waters are used for municipal and industrial water supplies.
5. The effects of untreated pollutants on industrial and domestic activities.
6. The effect of each pollutant on fish and wildlife support capabilities.
7. The relationships between recreational usage and water quality, i.e., contact and noncontact water based recreational demand and water quality.

8. Effects of each pollutant on the useful life of each reservoir and lake.

9. Effects of each pollutant on health.

10. Effects of each pollutant on final receptors such as Lake Erie, Gulf of Mexico and oceans.

11. Establishment of regional functions relating degree of treatment and resulting water quality.

Specific Priorities

The state of the arts review has uncovered many specific areas and tasks that need to be substantially extended if an equitable solution to the water quality management problem is to be achieved. The most critical of the needs and priorities are summarized below. A more comprehensive listing is included in Section I of the text.

1. Development and implementation of appropriate methodology and procedures capable of providing direction and guidance in an area that has typically been problem-project-crisis oriented. This may well be accomplished by extending and refining the priority listings and benefit matrices presented in Appendix A.

2. Further development of appropriate water quality associated methodologies including items such as substitution effects, relationships between treatment and resulting water quality, aggregation procedures and inter-basin relationships.

3. Further development, extension and application of procedures capable of assessing ecological, esthetic and recreation associated water quality impacts.

II. A Methodological Approach

Preliminary examination indicates that health, production and municipal uses cannot be considered to be the source of large benefits of water quality improvement. It appears that the only way pollution abatement measures can be justified in a benefit cost framework is through the accurate assessment of recreation and esthetic benefits -- which are not possible at the present time.

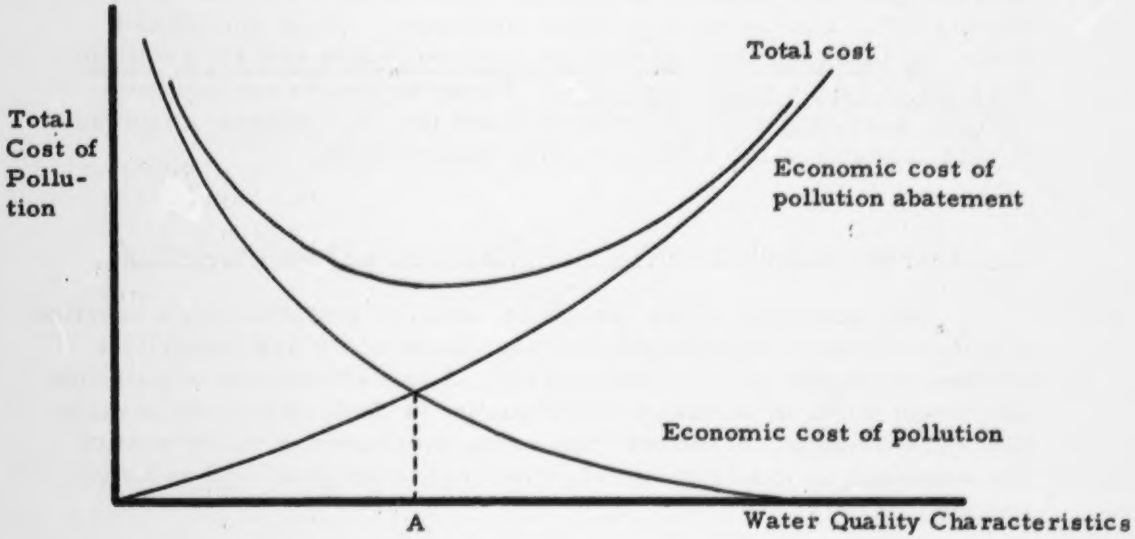
With the present inability to accurately measure and assess intangible and indirect benefits, the question arises of how to best serve the true social objectives. This can be accomplished more directly by casting water quality management in an alternative conceptual framework -- a cost minimization approach. Costs include both treatment costs and damage costs, e.g., damages, efficiency reductions and opportunity costs.

Since the primary source of the pollution problem stems from externalities or avoidance of on-site costs, the proper approach is to consider and minimize all costs (both on-site and off-site). The off-site (economic costs of pollution) vary inversely with the level of water quality. In the total absence of control the economic costs of pollution are at a maximum and at total control the economic costs are at zero (Exhibit 1). The second component of total social cost of pollution is the cost of pollution abatement as shown at the zero level with no controls in place and increasing as controls are enforced. The social objective can be maximized by selecting the water quality level which minimizes the total water disposal cost such as point A in the Exhibit.

III. Economic Cost of Pollution

The economic cost of pollution involves multidimensional components. Economic costs are dependent on, for example, specific beneficial water uses, specific pollutants involved and geographic location. This requires disaggregation of the problem in order to derive useful economic cost estimates. Further, then, aggregation schemes are necessary to derive national economic cost estimates and functions.

Exhibit 1. Total cost of waste disposal.



Four broad areas of beneficial water use are health, production, esthetics and ecology. Specific kinds of impact of water pollution among various beneficial use classifications are presented. The types of economic cost which may occur are damages, efficiency reductions, process changes, added expenses and opportunity costs.

Estimation procedures for estimating economic costs of pollution are discussed. An example of the cost of municipal preuse water treatment in relation to alternative levels of water quality is discussed. From this relationship the economic cost of pollution (damage) is derived. Other examples of estimation of economic costs are cited.

IV. Cost of Pollution Abatement

Procedures for establishing regional or national cost of pollution abatement functions are summarized and limiting factors noted. Current data and extensions (Appendix A) are then used to generate national pollution abatement cost estimates for all municipal and industrial secondary water treatment. On an annualized basis, national pollution abatement cost estimates are $3.9 billion for 1968 and $4.6 billion for 1976. These estimates include total capital, operating and maintenance costs (in 1967 dollars) required to meet standards for 1968 and 1976, respectively.

V. Estimating Water Quality as a Function of Pollution Control

The economic costs (damages, etc.) of pollution are a function of water quality whereas pollution abatement costs are typically a function of degree of pollution control. A transformation of pollution abatement costs in terms of water quality is desired for comparable cost comparisons. However, numerous measures of water quality are available including physical, chemical, biological and esthetic properties.

Measuring Water Quality

Problems encountered in measuring water quality are outlined and different measurement systems are discussed. Given a set of water quality measurements, it is still necessary to classify these measurements to rank the quality of water. Selected classification systems for water quality are also described.

Determinants of Water Quality

A primary determinant of quality is the quantity and type pollutants entering a water receptor, but of equal importance is the inherent waste-assimilative capacity of surface water. Consideration of composite relationships are therefore required.

A variety of sources of surface water pollutants, i.e., meterologic, domestic, industrial and agricultural, are discussed, as are the major quality impacts of each.

Measuring Water Pollution Control Levels

Conventional means of measuring or classifying the degree of pollution control has created some methodological problems toward estimation of water quality. Most frequently degree of pollution control is stated as a percentage or proportion of one or more pollutants removed from effluent flows. Absolute measures of raw effluent flows (including concentrations) into surface waters must be made, however, if water quality estimates are to be derived.

Aggregation

Measurement of either water quality or degree of pollution control involves a variety of aggregation problems. Spatial distributions of water, temporal aspects (including seasonal flows within a year), the nature and variability of wasteflows, and variations in treatment facility-effectiveness are among the problems encountered when aggregating water quality and degree of pollution control measures.

Water quality indexes tend to compound aggregation problems. A conclusion for this study is that water quality should be measured via specific pollutant values rather than an index.

Recommended Approach

An approach is recommended for relating degree of pollution control to water quality within a national water pollution control assessment framework based upon partial equilibrium and short-run planning constraints.

The recommended approach is illustrated for a case study from secondary (plus hypothesized) data. Tranformation curves and functions are shown.

The transformation functions developed are shown to shift over time assuming increased economic activity and population growth. The result is an expected increase in degree of treatment to maintain the same level of water quality. Because of the higher cost of improved degrees of treatment (constant technology assumed), the maintenance of a given level of water quality becomes more difficult to economically justify over time (constant per capita benefits also assumed). These latter conditions are readily identifiable using the degree of control/water quality transormation approach developed.

VI. Conclusions and Directions of Needed Study

The final chapter first presents a series of general conclusions. Also presented are selected possible areas of emphasis for continued work. Three areas of research recommended for immediate emphasis are briefly as follows:

1. Development of methodology to assess such problem areas as--
    a. Substitution effects
    b. Treatment versus quality transformation functions
    c. Aggregation schemes.
2. Refinement of pollutant/ receptor benefit matrix relationships (as initially developed in Appendix A) to better achieve priority rankings of areas requiring the greatest attention.
3. Development of procedures and methodologies to identify and quantify ecological, esthetics and recreational benefit impacts of water pollution control.

Appendix A: Appraisal of Cost of Control and Benefit Estimates

A special effort was made to develop specific benefit and cost estimates and related information as presented in Appendix A. This appendix concentrates on: (1) municipal and industrial pollution abatement costs (nonpoint sources were not included), (2) the relative importance of a series of beneficial water uses, and (3) the relative importance of various specific pollutants.

Municipal and Industrial Pollution Abatement Costs

Estimates of wasteflows, concentrations and wasteloads are presented for 1968 under no treatment, prevailing treatment and current standards treatment assumptions. Even with 100 percent compliance with current standards, substantial quantities of pollution would be contained in treated effluents.

Abatement capital costs for 1968 flow conditions are estimated as: (1967 constant dollars)

a. prevailing levels -- over $14 billion
b. current standards in 1968 -- nearly $26 billion

Estimated 1976 costs for full compliance (in 1967 constant dollars) are over $30 billion capital replacement value and $4.5 billion annual costs (including annual capital cost).

Importance of Beneficial Water Uses

Past studies indicate benefits are distributed as follows (ignoring health, ecological, intangible esthetics and agricultural irrigation):

Beneficial use	Percent of total benefits
Municipal preuse treatment	2.6 - 28.9
Domestic use	0 - 31.7
Industrial use	3.5 - 21.6
Navigation	0 - 2.8
Commercial fishing	0.0
Total production	17.3 - 75.9
Recreation	23.0 - 77.8
Property values	1.2 - 21.8
Total tangible esthetics	24.1 - 82.7

The above benefit distributions reflect recreation benefits in total before substitution effects. Adjusting for this factor by assuming 50 percent would be left after substitution and by estimating the relative magnitudes of the beneficial uses ignored in those studies, DPRA developed the following subjective estimates of benefit distributions:

Beneficial use	Percent of total benefits
Health	4.0 - 4.5
Production	
Municipal preuse treatment	10.0 - 12.0
Domestic use	12.5 - 14.0
Industrial use	8.5 - 11.5
Irrigation & animal health	3.0 - 4.0
Navigation	0.5 - 1.5
Commercial fishing	0.1
Total	37.1 - 40.6
Tangible esthetics	
Recreation	17.0 - 18.5
Property values	1.5 - 2.0
Total	18.5 - 20.5
Ecological & intangible esthetics	36.9 - 37.9

Expansions of the benefit distributions to national estimates of total social welfare benefits were not attempted due to state-of-data limitations and methodological considerations.

In terms of research priorities, we rank the beneficial uses as follows with the most important first:

1. Ecological and intangible esthetics
2. Recreation
3. Municipal preuse treatment
4. Domestic use
5. Industrial use
6. Health
7. Agricultural irrigation and animal health
8. Property values
9. Navigation
10. Commercial fishing.

This ranking is based both on percentage distribution of benefits and pollutant damage potential considerations. To assist in this task, a pollutant-beneficial use damage potential matrix was developed to reflect known and suspected pollutant-use relationships.

Importance of Specific Pollutants

Based upon a percentage benefit weighted pollutant-beneficial use damage potential matrix and subjective estimates of national pollution prevalence and intensity by specific pollutant, research priorities were subjectively ranked as:

1. Organics -- BOD, COD
2. Nutrients -- nitrogen, phosphates
3. Suspended and dissolved solids
4. Turbidity, pH, temperature
5. Fecal coliforms, oil, toxic substances, floating solids, color, odor
6. Hardness, taste, radioactivity.

SECTION I

BACKGROUND PERSPECTIVES AND RESEARCH NEEDS

A. Introduction

This document summarizes developments for the second part of a three-phased program of study:

Phase I:	State-of-Art Review
Phase II:	Specification of Research Needs and Priorities
Phase III:	Selected Implementation Research

A separate state-of-the-art literature review report (4) was presented summarizing various methodologies and procedures that have been developed and utilized in assessing the economics of water quality management.

The objectives of this segment of the project are to (1) establish research needs and priorities for estimating benefit and cost-of-control functions relative to policy needs--independent of data and methodology contraints, (2) to establish research needs and priorities for estimating benefit and cost-of-control functions relative to policy needs--given data and methodology constraints, (3) to further analyze and evaluate selected studies that have undertaken the formulation of area water quality associated benefit cost estimates or functions, (4) to further supplement and refine water quality associated benefit cost methodology, (5) to explore alternative procedures that may be more appropriate to the water quality management problem and (6) to suggest possible areas to be emphasized in future research.

The above objectives represent a considerable extension beyond the intended effort. This, however, is an inevitable by-product of the formulation of research needs and priorities and the detailed assessment of the relative merits of existing work. The state-of-the-arts must be followed by a critical evaluation.

Both tasks, i.e., state-of-the-arts review and a critical evaluation, are requisite inputs in the development of research needs and the assignment of research priorities. Further, the research needs and priorities can be formulated only when an adequate analytical framework or general technique has been selected, developed or as in this case, refined.

To successfully accomplish the above objectives, it is expedient to first outline the primary management problem; and, second, to evaluate the contributions and relative merits of existing work beyond the state-of-the-arts presentation. Complementary research needs and priorities are subsequently formulated.

B. Primary Resource Management Problem

The primary problem or shortcoming of the present system from which almost all environmental problems emanate is the inability of the market system to efficiently allocate common property resources (this includes the temporal allocation of resources). This deficiency is inherently tied to the concept that certain resources are not owned individually but considered free. Title is acquired only through capture (fugitive resources).

This notion of free resources implicitly means that the market system does not and is not capable of placing a value on these resources. Efficient allocation and utilization of such resources may be difficult in the absence of market prices or private efficiency incentives. In some cases the present social system actually encourages inefficient allocation and utilization of resources. Individuals mining groundwater in areas anticipating pumping restrictions based on historical usage, for example, are encouraged to extract resources beyond the point of positive net marginal value in an attempt to protect future pumping privileges. Further, a variety of studies have established that industrial water users are seldom charged a price for water which is equal to the marginal cost of providing water or the marginal costs of contaminating the water. (1)

While these examples are related to quantity rather than quality aspects of the problem, both issues are part of the broader resource allocation question and serve to reinforce the fact that private incentives governing efficient resource use and allocation are not provided by the market mechanism or any other outside source. Some have been tempted to summarize the problem with one word--externalities. While this is perhaps an overstatement the internalization of all water quality associated costs and benefits would eliminate a substantial portion of the problem. It must be emphasized that externalities are actually the result and not the source of the problem.

In the absence of efficient market allocations, proper corrective measures must be implemented. This means that some socially responsible agency (presumably the Federal government) is beseiged with the problem of either revising the market system to encourage efficient common property resource utilization or of providing adequate incentives exogenous of the market system.

Proponents of the market system have historically advocated the merits of the former approach. Others, recognizing the difficulties of such an undertaking have recommended the latter. The source of the incentive is beyond the scope of this section. However, it is recognized that some attempts must be made to account for this deficiency if the water quality management problem is to be solved. It should be further recognized that the difficulty encountered in either approach is that of developing a policy or framework that produces optimum results, i.e., overpricing or underpricing effluents would not produce socially optimum results, thereby adding little to the solution of the overall problem.

While the complexities and complications are great and the alternatives are many, a slight digression into specific attempts to provide the financial incentive inherently lacking in the market mechanism will further illuminate the basic problem.

Since the postulation extended is that the market system fails to include all costs of production (externalities) including waste disposal, a financial penalty that makes it at least as expensive to dump untreated waste into the environment as it is to pay for waste treatment should contribute to environmental cleanup. Operationally, the financial penalty may be in the form of a fine, a tax on the end product, or a system of charges of so much per ton of waste discharged. Financial rewards (subsidies) for waste treatment are the reverse of penalties and are similar from an analytical viewpoint.

Fines or threat of fines are frequently used to enforce compliance with environmental standards. Fines with or without an injunction that forces closure can be severe enough to accomplish the objective of waste cleanup. This alternative does have disadvantages. First, the fine comes after the fact. Not only does excessive pollution occur but considerable delay may be expected before action is taken to remedy the situation. Litigation proceedings are never swift and the growing list promises to be both expensive and time consuming. Also, fines probably create more ill will than any other procedure. No one likes to be publicly censored or forced to endure court proceedings which question innocence. Fines can therefore be expected to lose as many friends of environmental causes as are won.

A tax becomes a more desirable alternative. Admittedly, it is difficult to estimate the amount of tax needed and it often has the added disadvantage of administrative complexity and expense. But the greatest impact of a per unit tax is on the consumption of a product whose production (and ultimate disposal) causes many of our environmental problems. Use of a tax on the consumer product or resources used in its production leads to a smaller quantity taken by consumers and simultaneously provides revenue for environmental cleanup.

Perhaps the most desirable financial penalty would be a surcharge or tax levied directly on the polluter discharging waste into the air or water. By levying a charge on waste in excess of "normal levels," business firms have an economic incentive to reduce the amount of water or air carried waste, thereby relieving the load on treatment plants. As an example of its effectiveness, a surcharge of 8 cents per pound of BOD in the city of Durham, North Carolina resulted in internal plant changes to bring about a 70 percent reduction in daily waste discharge. (2) Further, it is an efficient alternative in that the worst offenders pay the largest share of abatement cost while the tax is small to those who have already attempted to reduce waste.

The charge method can, through a series of approximations, be set to bring about a specified stream or air standard. A charge also brings continuous pressure to update waste technology. Its effects are felt at all levels of waste discharge where a standard may be set to bring no change to minimum level polluters or provides no incentive for change below the required level. The charge is desirable from an economic view in that firms recognize it as a cost of doing business and adjust to it on a marginal basis.

Even though a tax system levied on an individual point-by-point discharge basis would be quite expensive to enforce and administer, that objection could be largely overcome by an across-the-board tax schedule applicable to all who discharge into a particular stream or air quality control region.

Environmental objectives may also be met by offering financial rewards rather than penalties. A subsidy for environmental cleanup could be any of several types. An investment tax credit or favorable depreciation schedule could be sufficient incentive to invest in equipment to reduce waste. Grants or tax credits could be employed to induce use of recycled materials while favorable credit terms to cities could pay for water and sewer facilities. Although the list of fiscal techniques could be extensive, the common thread is meeting environmental cleanup objectives at public expense rather than the expense of business firms or local governments.

Subsidizing environmental cleanup carries distinct disadvantages. Of first importance, the worst offenders are those most rewarded and therefore the subsidy is objectionable on equity grounds. The prospect of receiving a public subsidy will frequently delay abatement programs until all avenues to the grant are exhausted. In fact, the subsidy alone does not guarantee cleanup. The polluter may choose not to take advantage of the lower cost, especially if there will be a large outlay in addition to the subsidy. Since the subsidy is not paid directly by the consumer of the final product there is no decline in quantity taken or no change in relative price of the product. While a charge may lead the business firm to make optimal adjustments to reduce waste discharge, with subsidy schemes, there is no comparable incentive to choose production methods that lead to less waste and there could be encouragement to do the opposite. Finally, financial penalties yield revenue while subsidies are a drain on the public treasury which must be defended each time budget approval is discussed.

The above material reiterates the need to provide financial incentives (endogenous or exogenous of the market system) into common property allocation and also provides several examples of such attempts. While it is not an exhaustive list of corrective measures, it is illustrative of attempts to solve the pollution problem by attaching the source of the problem, i.e., the introduction of exogenous financial incentives to provide the impetus to efficiently allocate and utilize common property resources.

It further emphasizes that the primary source of the pollution problem can be traced back to the lack of a complete market system. Additional research is needed to develop and explore various alternatives to alleviate this intrinsic deficiency. We have no allusion in respect to the magnitude of the task proposed nor are we suggesting that this be the first undertaking. There is no doubt, however, that the problem is bound in these terms and an effective and lasting solution cannot be reached without directly facing these issues. To this end we merely state that all other problems are secondary to this primary problem of common property resource allocation and that the long run needs do not necessarily have the highest priority in the short run. It does appear, however, that a great deal of effort has been expended in a symptomatic treatment of pollution problems without recognition of the basic problem.

C. Critical Evaluation and Summary of Existing Water Quality Management Literature

For the purposes of the following discussion, the evaluation of water quality associated models and procedures shall proceed on the following basis:

(1) Evaluation on a theoretical basis
(2) Evaluation on an implementational basis
(3) Summary statement

Evaluation on a Theoretical Basis

The evaluation of economic models and procedures associated with water quality management on a theoretical basis could lead far afield by attempting to discuss the intricacies of a large number of specific models. The desire here is to provide a general summary evaluation on a theoretical basis and such temptations must therefore be avoided by developing an alternative delineating criteria other than numerous theoretical and methodological considerations of specific models.

One such delineating criteria is to segment the approaches into two broad categories based on the level at which they address the water quality management problem, i.e., general equilibrium as opposed to partial equilibrium analysis. For the present purposes this distinction is more manageable and meaningful than delving into specific methodologies, procedures and assumptions of specific models. This taxonomy is further desirable for present purposes in that all approaches are, by definition, either general or partial in nature, thereby providing a natural circumscription. for the general summary that follows. The basic distinction is that the partial equilibrium models consider only a subset of the total problem while the general equilibrium models are concerned with the problem in its entirety (including secondary as well as primary impacts as they affect the total area or national economy).

General Equilibrium Analysis

The general equilibrium methods discussed in Phase I included the following specific models and types of models:

(1) Material-Process-Product Models
(2) Ecologic-Economic Models
(3) Kneese Model
(4) Input-Output Models, and
(5) Systems Analysis

These models, as well as other general equilibrium models, have the advantage of placing the water quality management problem in its proper conceptual setting by considering the entire problem with all of its various interactions. The problem is normally viewed in a highly aggregated framework perhaps even to the point of considering welfare maximization objectives involving social (public) choice and public decision making. This general approach is further intuitively pleasing in that it is consistent and compatible with the approaches to welfare maximization in general. It is also desirable since it is complementary to natural-physical relationships suggesting that all resources are interrelated and intertwined further indicating a "general" or biosphere approach to resource management should be adopted.

The proponents of general equilibrium approaches further suggest that only at the general equilibrium level can the relevant economic and ecological considerations, decisions and trade-offs be effectively evaluated in arriving at desirable national (or even global) resource management objectives and subsequent policies designed to achieve these objectives. Water quality induced price changes (output and input prices), production shifts, process changes, interindustry interaction and all other second round or secondary effects of environmental degradation or alternatively, pollution abatement standards, must be assessed if definitive results are to be realized. These impacts are visible only when the problem is structured in a comprehensive or general equilibrium framework.

Studies that have utilized general equilibrium methods have succeeded in quantifying sizeable and in some cases unanticipated secondary impacts. (3) For this reason unquestioned reliance on partial equilibrium studies could result in misdirected and unwarranted results and priorities. The general equilibrium models must, therefore, be preferred to partial equilibrium models if the selection is based solely on theoretical considerations.

It must be realized, however, that the general models are in an embryonic stage of development as a water quality management tool. Most attempts to develop general models actually involve adaptation of previously existing general equilibrium models. Their success as a practical water quality management tool (at the present time and stage of development) is somewhat less than satisfactory. They have been applied to small geographical areas with varying degrees of success but have not been developed, refined or applied to assess water quality associated impacts on a national basis.

One intrinsic disadvantage of the general models is that the highly aggregated or general approach obscures a significant amount of detail. The amount of detail lost may be sufficient enough to prevent the approach from becoming a viable water quality management tool. (The validity of this criticism may not be universally accepted since it is also the general approach and high level of aggregation that permits and enhances the comparison of various alternatives and trade-offs required to maximize net social welfare.) There are many natural and physical water quality related constraints and considerations that are not amenable to high levels of aggregation. While it is true that economic considerations may best be assessed through general equilibrium methods, the judicious incorporation of numerous natural and physical considerations ineluctably involved is not achieved through the use of extensive aggregation or general equilibrium methods.

The question becomes one of deciding which approach is feasible in the short run and is also complementary to the solution of the problem in its long run comprehensive setting. Unfortunately, data constraints and the present state-of-knowledge prevents the general models from being considered readily accessible, viable water quality management tools that can be implemented in the short run.

Before leaving the general models, it should be added that river basin simulation models appear to possess a considerable potential for becoming a useful and comprehensive management tool by approaching the problem within a comprehensive river basin framework applied to a specific hydrologic area. The adoption of this technique enhances the possibility of incorporating complex water quality and hydrologic characteristics of specific areas into a meaningful framework thereby further increasing the likelihood of accurately assessing complex intertwined water quality associated impacts. The identification and quantification of these interrelated physical characteristics further facilitates a definitive assessment of the economic impacts. Since it is also possible that pollution abatement standards will, by necessity, be source oriented, any attempts to quantify effluents by type, source and geographic area will also facilitate the implementation of spatially dependent pollution abatement standards. The river basin simulation model is one practical way to deal with the comprehensive water quality problem within a framework that is capable of incorporating complex hydrologic relationships. It must be realized that at the present time, this technique has been applied to only selected basins and subbasins with the general application of this procedure to all major river basins remaining relatively unexplored and incomplete.

It is also interesting to note that one other general equilibrium approach to water quality management has frequently been utilized by various research groups. This method is input-output analysis. The complex interindustry impacts of deteriorating water quality or pollution abatement standards can best be identified and quantified with the aid of this method of analysis. While the river basin simulation models are perhaps more sensitive to the hydrologic relationships within a region, input-output analysis is best suited to quantifying complex interindustry relationships.

A word of caution is also in order at this juncture. The quest for national water quality associated benefit and cost of control estimates and functions has prompted some to generalize previously completed area studies to acquire the desired national estimates. It must be realized that spatial differences in economic activity, hydrologic conditions, as well as extreme variations in prevailing water quality and water quality requirements severely limits the value and creditability of national estimates or functions acquired in such a manner. The methodological and theoretical assumptions appropriate for small area studies are not necessarily appropriate when larger geographical areas are considered. Such attempts are, therefore, acceptable only if the limitations and dangers are explicitly recognized and if more acceptable methods are unrealistic due to time and effort constraints. When faced with a similar problem, M. M. Kelso reached a most appropriate conclusion:

> Man is damned forever to partial incremental choice criteria, in part because of the limitations of his finite mind and in part because the peak criterion in his collective choice must be objectified, verbalized and quantified, distilling away some of the subjective value feelings implicit in ultimate goals.
>
> The economic analyst serving as an expert consultant to the public decision maker is doubly damned, not only to partial incremental choices, but to working with only a few sub-set criteria within the two sub-class criteria of economic efficiency and economic equity. He is restricted to sub-sets so few that he can handle their complex interrelations and so sharply delineated that he can sense them clearly and quantify them accurately.
>
> The practical consideration for us as economic analysis is how partial must we be? (4)

Partial Equilibrium Analysis

The second type of approach based on the above taxonomy is partial equilibrium analysis--partial in the respect that no attempt is made to view the entire problem with all of its ramifications and implications. These studies characteristically incorporate various methodologies and procedures tailored to isolating and studying certain facets of the water quality problem in detail. In general, they tend to be problem-project-crisis oriented in nature in that they typically are concerned with estimating or quantifying only a small portion of the primary or first round impacts that are of immediate interest or importance. Many of these studies are therefore differentiating in that they assess various water quality repercussions without regard for how the results or methods contribute to the solution of other questions or contribute to the total.

While these models are adequate for the particular problem they are addressing, it must be kept in mind that they are partial in nature and as such are not designed to assess the total impacts of water quality deterioration. There is a temptation to apply these approaches to the solution of the total problem by aggregating the results of various partial studies to achieve national water quality associated benefit and costs of control functions. Since these studies and methods are designed to satisfy or answer only isolated microeconomic aspects of the problem, such attempts to aggregate are inevitably subject to methodological criticisms. For example, a variety of studies have assessed the impacts of water pollution or pollution abatement standards as applicable to a particular industry. These studies frequently assume constant (input and output) prices, production patterns and processes. Under these rather restrictive assumptions, industry impacts can be accurately assessed. When, however, all industries are subject to pollution impacts or abatement standards or water quality deterioration simultaneously, the derived results are no longer applicable due to the violation of the study assumptions, i.e., the constancy of relative prices, production patterns and production processes. The fallacy of composition is quickly encountered. By changing the scope of the problem (attempting to sum various partial studies), the problem itself changes. The partial studies are by-and-large essentially nonadditive, and somewhat noncomparable in nature due to variations in methodologies, procedures and assumptions.

It is also surprising and perhaps shocking to search the literature and discover the very limited number of partial equilibrium studies that have attempted to identify and quantify comprehensive first round water quality associated benefits and costs. In all the literature that was reviewed for Phase I and II, very few "comprehensive" partial equilibrium studies materialized.

One of the many techniques that have been utilized in partial equilibrium analysis has been the cost benefit analysis. The following material included in Phase I as a summary of the weaknesses of traditional benefit cost analysis for dealing with environmental quality issues, is applicable to the evaluation of any and all partial equilibrium analysis as an approach to water quality management:

> Traditional benefit cost analysis has numerous short falls as a management tool to evaluate policies designed to improve environmental quality.
>
> "Most benefit cost approaches are inadequate not because there is anything wrong with using a benefit cost ratio per se, but because frequently the benefit estimations, a good many of the cost estimations, the treatment of uncertainty, and all of the time discount rates are improperly derived." (Whipple, 1971)
>
> Two general limitations of benefit cost analysis have been concisely summarized by Prest and Turvey (1965). "First, cost benefit analysis as generally understood is a technique for taking decisions within a framework which has to be decided upon in advance and which involves a wide range of considerations, many of them of a political or social character. Secondly, cost benefit techniques as so far developed, are least relevant and serviceable for what one might call large-size investment decisions. If investment decisions are so large relatively to a given economy..., that they are likely to alter the constellation of relative outputs and prices over the whole economy, the standard technique is likely to fail us, for nothing less than some sort of general equilibrium approach would suffice in such cases."

> The Prest-Turvey critique implies that benefit cost analysis can be applied to environmental problems only with great difficulty and may be conceptually and empirically inappropriate.

> Traditional benefit cost analysis has evolved as an analytical device for measuring development effects rather than environmental repercussions. The result is that a general conceptual framework for evaluating pollution abatement policies has not been formulated which has received a generally favorable review. The major difficulty revolves around the identification and measurement of benefits from pollution abatement. Traditional benefit measures used in evaluating development projects have limited application to environmental repercussions because they have failed to embody externalities on affected processes. It is noted, however, that development effects are also a major component of social welfare. Both private and public aspects are involved. (5)

The evaluation solely on a theoretical basis has produced two diametrically opposed results. The general equilibrium models view the water quality management problem in a proper conceptual framework, possess enormous data input requirements and enables basic trade-offs to be evaluated. The final output in its aggregated form especially considering the present state of development has the disadvantage of lacking sufficient detail required to be a viable water quality management tool.

On the other hand the partial equilibrium models do not address the water quality management problem in a proper conceptual framework. Even the most fundamental trade-offs occasionally escape the analysis. They are, however, more detailed and amenable to the spatial economic and hydrologic characteristics embedded in the water quality management problem than are the general equilibrium methods.

All water quality management models or studies may be classified as general or partial equilibrium due to the tautologous nature of the classification scheme adopted. Unfortunately, however, the associated merits and resulting recommendations emanating from such a classification scheme are not as straightforward and concise as the classification scheme itself. The search for immediate answers dictates the adoption of an adhoc procedure utilizing the strengths of both types of models, i.e., from the partial equilibrium studies functional estimates of water quality associated benefits--interpreted as first approximations--may be obtained and subsequently tempered, conditioned and interpreted with the insight gained from selected general equilibrium studies.

Evaluation on an Implementational Basis

An evaluation on any other basis other than a theoretical basis may be subject to some criticism in that either an approach is theoretically sound and should be pursued or theoretically deficient and should be abandoned. Statements similar to the above, as well as other methodological decision rules, have considerable appeal; however, there are a variety of reasons justifying continued development of the partial equilibrium models as a means of acquiring national water quality associated benefits and cost estimates.

The reasons for this are obvious. First, the complexity and magnitude of the water quality problem with many presently unknown and unidentified relationships frequently necessitated the adoption of very pragmatic simplified and approximating procedures. The level of effort associated with general equilibrium analysis is frequently staggering and completely prohibitive. Secondly, many of the functional relationships required in a comprehensive or general equilibrium study are presently lacking, i.e., many of the first round or primary impacts and relationships are not understood or specified and frequently these relationships are essential inputs in the construction of general equilibrium models. Thirdly, many studies must be concerned with the local impacts of water quality deteriorations and as such must adopt partial equilibrium methods as opposed to general equilibrium methods due to the inherent difficulties of adopting general equilibrium technique to the evaluation of economic impacts of small geographical areas. Lastly, there are many aspects of the water quality management problem that have to be approached on a disaggregated level. For example, desired water quality depends on beneficial use (withdrawal, nonwithdrawal, consumptive and nonconsumptive use). Since water use is spatially dependent and water qualities vary from area to area, the imposition of a universal water quality standard is not consistent with basic economic efficiency objectives. The quintessence of the above items is that there are many considerations which tend to indicate that water quality items may have to be viewed and analyzed with partial equilibrium techniques as a first approximation to the eventual solution.

It, therefore, appears that both types of approaches (general equilibrium and partial equilibrium) have their own respective strengths and limitations which differ drastically when different criteria (theoretical as opposed to implementational) are used in the evaluation process.

Summary Statement

Before proceeding to other considerations, it is perhaps desirable to summarize in general terms some objective and subjective conclusions that have been formulated as of this point.

In general, there is evidence of considerable lack of direction and coordination in the water quality management literature. This limitation has been recognized by others and is succinctly summarized by Kneese and Bower (1968). "In most regions, water quality management is at a primitive level. At the same time, the technical and analytical means for implementing such systems are developing rapidly. The institutional means lag far behind." (6)

There is also the failure on the part of many to recognize the primary source of the environmental quality problem which inevitably leads to a symptomatic approach to the problem rather than a direct confrontation of the major factors involved in the water quality management problem. More precisely, many partial equilibrium studies delineate various aspects of the water quality management issue for detailed analysis without regard for how the particular segments can be fitted together to portray the total picture. Many of the partial equilibrium studies are highly project-problem-crisis oriented and contribute very little to the derivation of national benefit and cost of control functions. This is further complicated by the fact that the partial equilibrium studies typically consider only a very small portion of the total first round or primary impacts of water quality deterioration. The cost or risks of generalizing or aggregating these studies to derive national benefit and costs of control estimates and functions may indeed be great. This is particularly true when one considers the extreme variation in area water qualities, effluent flows, assimilative capacity and economic activity.

Neither approach (general or partial) has been adequately developed so as to be a readily available tool applicable to the problem at hand (derivation of national water quality associated benefit cost estimates and functions). The general equilibrium approaches currently lack the requisite data input and the partial equilibrium studies have not corrected this basic deficiency by providing the required functional relationships and data input in general. This paradoxical and circuitous conclusion is a rather uncomfortable summary of the effectiveness of past endeavors considering the urgency of various water quality management tasks. A unified sense of direction and coordination satisfying both long run management objectives and short run goals must be developed.

An appropriate summary is provided by Professor Kelso. "The complexity of multiple sub-set mixes together with the difficulties inherent in analysis of the effects of investment on the total economic system in space and time has led analysts such as Professor Wantrup and Lindblom to reject any notion that maximization of a peak criterion is possible and to assert that the best man can do is to make his partial comparisons among an available array of alternatives and to choose the one which appears in the light of present considerations to generate consequences that move in the direction of the preferred state at an acceptable rate of speed and sacrifice." (7)

Arthur Maass has likewise concluded, "After the agencies have learned how to work with two-term objective functions, they can try to solve for more complex ones." (8)

D. Research Needs and Priorities

The statements above outline the primary environmental management problem and assess the principal existing water quality management literature. With this foundation, attention is turned toward establishment of research needs and priorities.

Acceptance of the primary problem is far from satisfying since it is realized that its solution would require an unacceptable long time frame. Many critical areas of water pollution cannot be postponed for this length of time. In the interim, partial or secondary problems must be addressed.

To facilitate further discussion, we have classified the secondary problems into two general categories: (1) data input needs, and (2) methodological and theoretical research needs. Subsequently, a summary of priority research needs are presented.

Data Input Needs

The solution of problems cannot be fruitfully pursued until the required data base has been provided. Water quality management problems are not unique in this respect. From the state-of-the-art review and the preceding evaluation of existing work presented in this report, it should be no surprise that cost and benefit data input constraints represents one of the largest obstacles that must be hurdled in the search of a satisfactory solution to the environmental management problem.

At the present time the physical, biological, chemical and engineering data input has not been provided in sufficient detail. Even though the effects of some pollutants have been identified and quantified, a comprehensive understanding of all natural and physical relationships associated with water quality is far from complete. These relationships must be established if the damages of deteriorating water quality or benefits from mandatory pollution abatement standards are to be assessed. The absence of such data input at the present time limits the accuracy of comprehensive national benefit and cost functions associated with deteriorating water quality and likewise severely limits the assessment of benefits accruing from water quality improvement.

Some of the physical, chemical, biological, economic and engineering data input needs include, but are not limited to, the following items:

1. Relationships between waste treatment cost and effluent water quality for each pollutant and for each type of industrial and municipal wastes.
2. The quantity of each pollutant from non-point sources which enters each receptor.
3. The extent of assimilation of each pollutant by natural processes in each receptor.
4. The effect of each pollutant on municipal and industrial water treatment processing costs where surface waters are used for municipal and industrial water supplies.
5. The effects of untreated pollutants on industrial and domestic activities.
6. The effect of each pollutant on fish and wildlife support capabilities.
7. The relationships between recreational usage and water quality, i.e., contact and noncontact water based recreational demand and water quality.
8. Effects of each pollutant on the useful life of each reservoir and lake.
9. Effects of each pollutant on health.
10. Effects of each pollutant on final receptors such as Lake Erie, Gulf of Mexico and oceans.
11. Establishment of regional functions relating degree of treatment and resulting water quality.

Without the knowledge of the above relationships, attempts to optimize regional or national water quality will be limited to a "hit and miss" basis without a well defined sense of direction. The results emanating therefrom will quite likely be highly suspect in the absence of basic well specified relationships such as those listed above.

Although a comprehensive understanding of all of the physical-natural relationships is not available at the present time and will not be in the immediate future. Efforts to fully utilize existing data are noticeably absent. Many problem-project-crisis oriented studies provide point estimates of benefits and/or costs of control associated with water quality while the development of functional relationships relating benefits and costs to specific undesirable water quality constituents, are basically lacking at the present time and represent a pressing constraint. This is particularly true of water quality associated benefit functions. There are a variety of reasons other than data availability that are responsible for this shortcoming. The existence of externalities, intangible and indirect effects, the lack of an acceptable aggregation scheme and an acceptable unit of measure valuing nonmonetary benefits has increased the difficulties of constructing a comprehensive composite water quality benefit function. The identification and quantification of these effects must also be considered an urgently pressing research problem.

Even though some consider the development of appropriate benefit estimation methodology and subsequent establishment of water quality associated benefit functions as perhaps the single most pressing water research problem, the establishment of a composite cost of control function also represents a significant research deficiency. While data availability is one constraint that must be eliminated or at least partially circumvented, the successful completion of these activities--establishment of both water quality associated benefit and cost functions--also hinges on the successful fulfillment of certain currently unresolved and unsupported methodological and theoretical and objective tasks.

Without the establishment of the above functional relationships, the area of concentration (specific pollutants, receptors and pollution sources), optimal timing of pollution abatement investment, optimization of regional and national water quality, and consequences of deferred action cannot be ascertained. While these functional relationships depend on data availability, certain methodological and theoretical implications are intrinsically involved and are of equal importance.

Methodological and Theoretical Research Needs

A series of general methodological and theoretical research needs are presented next without regard for data and methodology constraints. These needs stem from the primary resource management problem as described above. Water quality management is required in a dynamic setting and over a broad range of hydrologic and economic conditions. The common property resource aspects of the problem with the prevalence of externalities complicates the issues involved. These and other factors are embedded in the general research needs below.

Some general methodological and theoretical research problems and needs (not listed in order of priority) include:

1. Development of methods and procedures to identify and quantify water associated benefit and cost functions relating specific benefits and costs to specific pollutants.

2. Development of economic and hydrologic models to identify and quantify complex intra- and interbasin relationships.

3. Extension and refinement of accounting measures, such as "insurance values," for uncertain water quality associated costs and benefits.

4. Formulation of a measure of value that can be used as a common denominator additive measure to effectively evaluate all intangible and indirect nonmonetary costs and benefits associated with changes in water quality.

(Since many of the potential benefits of water quality protection or improvement are intangible and indirect esthetic, health and ecological benefit that are not measured by market transactions, an accurate estimate of composite benefits is not generally possible within present day methodologies.)

5. Development of alternative pollution abatement policies designed to minimize undesirable equity and distribution impacts associated with water quality control.

6. Quantification of complex water quality substitution effects. As water quality deteriorates, certain substitution effects may be expected. Water using activities and processes will begin seeking alternative input sources, processes and outlets as water quality deteriorates. For example, water quality degradation will directly and indirectly encourage reduced expenditures on water based recreational activity. The reduction in water based expenditures represents a loss to this sector of the economy. If one is interested in national impacts of water quality deterioration, the correct figure is not the total reduction in only water based recreational expenditures but rather the net reduction or impacts associated with the change in total recreational expenditures, i.e., explicitly recognizing the substitution phenomenon. These complex relationships must be further developed if realistic national benefit and cost of control functions are to be established. (9)

7. Development of an aggregation framework to assess regional and national pollution control costs and benefits.

8. Assessment of alternative political, legal and institutional arrangements needed to perform water pollution control management functions.

9. Development of procedures to project and evaluate alternative distributions of benefits and costs through time, i.e., "time profiles," including the use of a social discount rate to compute present value.

10. Estimation of net social benefits attributable to water pollution control measures, i.e., measurement of a social welfare function. Water pollution control measures are expected to impact economic structures with consequent relative shifts in supply and demand relationships. Such consequences call for analysis of the social welfare function.

The above list includes a variety of methodological and theoretical research needs, some of which suggest that a substantial reassessment of commonly held social objectives is in order. The listing is presented in broad terms and unstructured in reference to the assignment of priorities. No attempt has been made at this time to indicate th priorities associated with these research needs or to classify them into short run or long run needs. What, therefore, remains to be accomplished is the establishment of research needs and priorities with data and methodology constraints.

Long Run Economic Research Needs and Priorities

The objective of this section is to provide a general summary of "ordered" research needs. (To the extent possible, the order reflects priorities for these research needs.) Many of these research needs and priorities are well documented while others are the product of Phase I and the subsequent evaluation. Long run and short run research needs and priorities are presented in summary and enumerated form below.

The long run economic research needs include:

1. Develop a comprehensive common property resource allocation system to assist in the efficient allocation and utilization of common property resources--endogenous or exogenous of the market mechanism. Alternative institutional structures are implicitly involved.

2. Further develop and implement general equilibrium models specifically designed to assess the economic impacts of changing water quality and mandatory pollution abatement standards.

3. Refine the above mentioned models until they possess the required degree of sophistication to evaluate complex trade-offs at the aggregate level but still possess the detail required to be useful regional water quality management tools. Incorporate measures to achieve dynamic efficiency realizing that production process, technology, demographic and social preference changes occur.

4. Develop a measure of value that can be used as a common denominator, additive measure of intangible or indirect water quality associated benefits and costs.

5. Develop "insurance values" or alternative measures designed to handle unknown contingencies associated with water quality determination.

6. Reassess and evaluate the social discount rate currently used in evaluating public investment projects.

7. Explore regional, national and international legal, institution and structural changes required for effective monitoring and surveillance of emissions and realization of environmental objectives.

The above hierarchy of long term economic research needs is somewhat misleading in that it is extremely difficult to assign meaningful priorities in that all are requisite to an effective and lasting solution to the environmental management problem. In the interim it is expedient to concentrate on less ambitious short run research needs and priorities.

Short Run Economic Research Needs and Priorities

The following items constitute economic research needs that could be at least partially satisfied in the short run given existing data and methodology constraints. The three major divisions and subdivisions are listed in their relative order of importance.

It should not be surprising to find that benefit estimation is the singularly most important need to be satisfied in the short run.

I. Develop, refine and implement methodology for assessing water quality associated impacts with special emphasis on the following short run research needs.

   A. Benefit estimation
      1. Refinement of overall benefit estimation methodology.
      2. Refinement and implementation of intangible benefit estimation methodology and techniques.
      3. Estimation of substitution impacts.
      4. Development of multivariate water quality associated benefit functions.
      5. Interfacing economic, hydrologic, biological and engineering water quality models.
      6. Estimation of irreversible damages.
      7. Development of a satisfactory aggregation scheme.

B. Cost estimation
   1. Refinement of overall cost of pollution abatement methodology.
   2. Development of nonpoint pollution estimate and cost of treatment.
   3. Development of a treatment versus resulting stream quality function.
   4. Further development of least cost treatment strategies.
   5. Development of cost aggregation framework.

C. Implicit in all of the above items is the development of a satisfactory data base including but not limited to the following items.
   1. Pollutant level by receptor
   2. Effluent flows by source
   3. Effluent flows by process
   4. Precise water quality monitoring data
   5. Damage thresholds and impact ranges
   6. Critical effluent levels
   7. Synergistic effects

II. Develop pollution abatement policy alternatives with special emphasis on the following items:

   A. Development of spatially variable policies and abatement standards.
   B. Minimization of adverse equity and distribution effects.
   C. Development of alternative policies to provide internal incentives to reduce effluent loads.

III. Analysis and inauguration of institutional and structural changes required to implement many of the above items.

Immediate Research Needs and Priorities

While all of the above items constitute short run economic research needs and priorities that could be eliminated given present data and methodology constraints, there is great disparity in the importance or urgency associated with each of these items. There is also the need to further develop and refine techniques useful in appraising short run priorities so as to insure that current resources and efforts are properly directed. For this reason those items representing the greatest need have been singled out and listed below:

1. Continue to develop, refine and implement procedures useful in ascertaining the most detrimental pollutants.
2. Continued refinement of water quality associated benefit estimation methodology.
3. Development and implementation of benefit estimation methodology appropriate for the estimation of intangible water quality associated benefits.
4. Investigation of complex water quality substitution effects.
5. Development and implementation of multivariant benefit function (relating benefits to several key pollutants).
6. Interfacing economic, biological, hydrological and engineering models.

E. Subjective and Objective Benefit and Cost Estimates

In addition to the above research needs and priorities there is considerable value to be gained in further summarizing and assessing the current status of benefit and cost estimates. For the most part these items are rather subjective and tenuous but possess considerable value in that the urgency of present action requires prompt and immediate deployment of pollution abatement measures in selected areas representing the greatest immediate and short run need. It is with this thought that a variety of subjective and objective water quality associated benefit and cost matrices have been developed and presented in Appendix A of this report. It should be recognized that this represents only a first approximation of what is presented as the number one immediate research need.

F. Directions of Further Study

The above material represents an extension beyond the state-of-the-arts review by providing a critical evaluation of the existing literature based on several delineating criteria. While this extension was not explicitly required, it must be either explicitly or implicitly considered in the development of the research needs and priorities. The specification of areas of needed emphasis further requires selection be made on the basis of current research development. The state-of-the-arts and the numerous complexities encountered seem to indicate that the water quality management task is an incessant project that requires further elaboration and extension at every intervening step.

This is indeed the justification for much of the remainder of this report. Detailed analysis of existing work has revealed many methodological shortcomings that should be addressed. The material that follows makes inroads toward the eventual solution of several current water quality associated methodological and theoretical problems.

In the subsequent chapters, the only type of approach that is considered is partial equilibrium analysis. Considering the current state-of-the-arts and level of effort considerations, this is the only feasible approach. Several partial equilibrium studies are reviewed in detail followed by various extensions. Alternative approaches possessing considerable merit are also developed.

Chapter II deals with general methodology in a partial equilibrium framework. Several partial equilibrium studies are appraised and alternative approaches and procedures are also explored. Most of the remainder of the report (Chapters, III, IV and V) is concerned with further elaboration of these techniques.

Chapter VI is a general summary of this phase of the project and proposed areas of emphasis for future research.

Footnotes

(1) Milliman, J. W.,"Welfare Economics, and Resource Development," in Ian Burton and Robert W. Kates (eds.), Readings In Resource Management and Conservation, the University of Chicago Press, 1965.

(2) Mangum, F. A., Jr., Policy Alternatives for Environmental Improvement, Department of Economics, North Carolina State University, 1972. (Unpublished Report)

(3) Hite, J. C. and Eugene A. Laurent, "An Economic-Ecologic Model for Evaluating the Environmental Repercussion of Area Development," American Journal of Agricultural Economics, Dec., 1971.

(4) Kelso, M. M., "The Criterion Problem in Decision-Making for Public Investment," Water Resources and Economic Development of the West. Report No. 15, Economic Criteria Water Transfer, Economics of Water Quality, Economics of Ground Water. Conference Proceedings, Committee on the Economics of Water Resource Development of the Western Agricultural Economics Research Council, Dec. 1966.

(5) Unger, S. G., M. J. Emerson and D. L. Jordening, State-of-the-Art Review: Pollution Control Benefits and Costs with Emphasis on Water, A report to the Environmental Protection Agency, Economic Analysis Branch, Washington, D. C., 1973.

(6) Kneese, A. V. and Blair T. Bower, Managing Water Quality: Economics, Technology, Institutions, Resources for the Future, Inc., John Hopkins Press, 1968.

(7) Ibid., Kelso, M. M.

(8) Maass, A., Benefit Cost Analysis:"Its Relevance to Public Investment Decisions," The Quarterly Journal of Economics, May 1966.

(9) In general, the substitution phenomenon referred to frequently in this report stems from the fact that there are alternative uses of capital in the economy and also that there are numerous alternative consumer expenditure outlets. This opportunity concept is frequently encountered but seldom recognized in studies assessing the economic impact of water quality degradation (primarily because most studies are problem-project-crisis oriented and are interested in ascertaining the economic impacts of water quality degradation in reference to only one isolated sector of the economy).

Kneese and Bower have, however, explicitly recognized this phenomenon in a discussion of a hypothetical example concerning markets, externalities and the social costs of pollution. The example assumes that pollution results in the destruction of a downstream fishing industry that utilizes resources valued at 100 and producing an annual return of 10. Upstream pollution results in the distinction of the industry and the conclusion reached is that "...the social cost of killing fish is 10 not 110 (market value of the fish), as is often implied in exhortations to assess waste discharges with the cost of damages they cause." (Reference 6)

The results, however, are predicted on the assumption that the resources can be transferred to other sectors of the economy at no cost to other productive uses at either the same or different locations.

This general concept, however, is particularly relevant and must not be overlooked when the goal is to assess national net social benefits of water pollution abatement or water quality associated benefit and cost functions. It is also hypothesized that this phenomenon is particularly important in water quality associated recreational activities in that there are a variety of outdoor recreational activities that are close substitutes for water based recreational activity. The increasing mobility of the population in general would seem to indicate greater flexibility in the selection of type and location of possible recreational substitutes.

The summary of this brief digression is that as water quality deteriorates, increased expenditures on skiing, camping, sightseeing, travel, tennis may be expected. The net social cost of water quality degradation must reflect this phenomenon.

SECTION II

A GENERAL METHODOLOGICAL APPROACH

A. Optimization of Net Social Welfare

The underlying objective of the relatively recent environmental quality thrust is not a new phenomenon but rather the interminable pursuit of the maximization of human welfare. In this respect the basic social objective has remained unaltered. The uninterrupted growth of national income and the unprecedented expansion of material wealth has permitted a reassessment of priorities resulting in a shift from material welfare objectives to intangible quality of life considerations. The basic objectives and tasks of the economist throughout the transitory period have, however, remained the same--developing criteria, analytical tools, decision rules and guidelines to aid and facilitate policy makers in their endeavors to develop policies and a general atmosphere conducive to the attainment of social welfare objectives.

The shift in emphasis has been accompanied by a host of complications and complexities that are rather tenuous in nature and difficult to assimilate into existing analytical techniques. A major portion of the complications arising from the shift in emphasis can be attributed to the need for establishing values and measures appropriate for and associated with numerous direct, indirect and intangible social welfare components. While there has always existed a need to consider, identify and quantify intangible social welfare components, the increased emphasis on non-material welfare has greatly increased this need. While the challenges are great and the obstacles are many, they must be overcome or circumvented one by one if a lasting and equitable water quality management solution is to be achieved.

It is difficult to think of another resource that has more social welfare implications than does water. Water is used in virtually every production process, it is an essential human and natural life support ingredient and further has certain intrinsic esthetically pleasing qualities in its unpolluted state. The degradation of water quality impairs its value in all uses in varying degrees. It is therefore difficult to conceptualize or formulate the water quality management problem in any other framework other than a social welfare maximization problem.

The salient point of the above at first glance may appear to be directing the discussion back to the general equilibrium as opposed to partial equilibrium controversy that has been encountered in Phase I and the preceding evaluation. This, however, is not the case as the only method of analysis to be encountered for the duration of the report is partial equilibrium analysis. The essence of the above is, however, that even though partial equilibrium analysis will be utilized (as the only practical approach at the present time), the acceptance or rejection of the welfare maximizing objective or goal has significant methodological implications. That is, the adoption of partial equilibrium techniques is an explicit recognition that many of the impacts of water quality degradation will escape quantification. This does not, however, require the relinquishment of ones obligations to recognize and consider various welfare implications that are normally disregarded in partial equilibrium techniques.

The vociferation by the general public for environmental standards, the subsequent establishment of the Environmental Protection Agency and the ensuing pollution abatement standards is certain manifestation that the general public desires and values environmental protection. It would, however, be foolhardy to assume that material welfare is no longer valued or a relevant welfare consideration. The final decision in reference to the desirability of pollution abatement standards must be based on total social welfare which is comprised of material wellbeing and other intangible considerations such as esthetic appreciation emanating from environmental quality enhancement. Any technique or method of analysis used to assess environmental degradation must therefore incorporate or consider as many facets of water quality impairment as possible or at least explicitly recognize those considerations that are relevant but not included because of data or state of knowledge constraints. Procedures that attempt to portray the total benefits of water quality enhancement without explicit recognition of the many limiting factors are truly derelict in their duty and oblivious of their true obligations. Any partial equilibrium techniques adopted must therefore constantly guard against becoming overly structured or limited thereby omitting numerous essential considerations. Several of the above precautions will be recalled as needed at various points in later discussions.

In addition to the above mentioned welfare considerations, there are a variety of other pertinent considerations that must be recognized preliminary to the discussion of specific estimation techniques that can be used to derive national water quality associated benefit and cost estimates. Some of these items are listed below.

1. The value of water is derived from its use (withdrawal, nonwithdrawal, consumptive and nonconsumptive--including intangible uses such as esthetic appreciation). The assessment of the impacts of water quality degradation must therefore proceed on an individual beneficial use basis since the individual uses are differentially impacted by water quality deterioration.

2. Since dissimilar pollutants in varying concentrations are more critical to some beneficial uses than to others, a specific pollutant by beneficial use assessment of water quality deterioration must be adopted.

3. The concentration of specific pollutants is equally important. If present in low concentrations, some pollutants have minimal damage potential while at higher concentrations their presence may significantly impair the utilitarian value of water. Other pollutants may be damaging at high and low concentrations with minimal damage at intermediate levels, e.g., florides. The assessment of damage potentials must therefore be with respect to a range of water quality levels if a meaningful assessment of net benefits is to be realized.

4. Since economic activity is not dispersed uniformly over the landscape and hydrologic conditions are also spatially variable, it follows from the above three items that varying spatially dependent water quality standards should be evaluated to assure economic efficiency and maximization of social welfare objectives. It also directly follows that benefit and cost estimates applicable to one geographical area may not be applicable to other areas.

5. By a complete assessment of both natural and man-made pollutants and area economic and hydrologic conditions, a social welfare area optimizing water quality could be conceptualized.

6. The maximization of water associated net social benefits dictates that optimal timing of pollution control expenditures, total impacts (primary and secondary), point of treatment and complex substitution effects be further examined in detail.

7. Combination of the above points suggests a potential danger in adopting universal industry and interindustry abatement standards irrespective of local economic and hydrologic conditions.

In the quest for a social welfare maximizing water quality solution, the first step may be in the direction of estimating benefit and cost of control functions. As suggested above, a number of important water quality variables exist. Suspended solids, dissolved oxygen, biochemical oxygen demand, coliform count, inorganic phosphate, nitrogen, pH, water hardness and dissolved solids are some of the more important variables. In searching for the optimum water quality in a particular receptor, each of these variables has certain costs and benefits associated with it. National estimates of net benefits must be with respect to a certain quality of water. Furthermore, it is well known that the optimum quality of water varies both because of natural terrain and human activity patterns. At Lake Tahoe the optimum quality is different from that in the lower portion of the Missouri river, for example. Because of this a procedure is needed which can lead to both an understanding of optimum quality in a specific basin as well as national estimates of net benefits.

The significance of the above is that water quality management, if couched in a social welfare setting, is not a single variate problem that can be easily portrayed in simple pedestrian terms. Water quality management is a multidimensional problem that must be formulated in a manner that is appropriate and consistent with multidimensionality. It is further possible that the unique spatial characteristics of water quality management and the multidimensionality in general may, in the end, be of such overwhelming importance that water quality management on a basis other than a small region by region approach may be self-defeating and totally void of meaning.

In view of the multiplicity of factors that must be considered, it is indeed not surprising that few have attempted to establish national water quality associated benefit and cost of control functions. The absence of such endeavors has left sizeable voids in the development of applicable methodology and estimation techniques.

B. Objectives

The fact that the development of national water quality associated benefit and cost functions is virtually an unexplored endeavor without precedence or frame of reference, the best approach may well be to seek out and review procedures and studies that have undertaken similar objectives on a regional scale. A thorough evaluation of such studies can be expected to provide considerable insight into the strength and limitations of such techniques. With this background, it may then be possible to adopt and extend these techniques and procedures to aid in the acquisition of national water quality associated benefit and cost functions or estimates. Another realistic alternative or possibility is that the limitations of such methods may be found to be of sufficient amplitude to discourage adaptation efforts in favor of developing alternative methods and procedures.

The objectives of the current chapter are to critically review and evaluate selected techniques, explore their potential as a national water quality assessment tool and to consciously seek out alternative procedures that are perhaps more amenable to the task at hand.

C. Related Studies

As has been previously mentioned, there is almost a total absence of studies that have attempted to establish water quality associated estimates by beneficial use on a national basis. This is not to say that national estimates do not exist for they do. By and large these estimates are the result of extrapolating the estimate of selected area studies. The merits and validity of these estimates can best be assessed by first evaluating the methodologies and techniques utilized to produce the regional estimates and secondly investigating the limitations and complications encountered in extrapolating these regional estimates to derive national estimates. The studies that are of primary interest are those that have undertaken the estimation of comprehensive benefits emanating from water quality improvement in specific basin, sub-basin, estuary or river reach considering a variety of beneficial uses and specific pollutants. This limits the selection to a very limited group of studies. Some of these include studies of water quality impacts associated with the following surface water bodies:

1. Ohio River Basin
2. Maumee River Basin
3. Delaware Estuary
4. Potomac Estuary
5. Yaquina Bay
6. Onondaga Lake

It must be pointed out at this juncture that these studies can not be considered to be representative of most areas of the country. The above geographical areas, with the exception of portions of the Maumee Basin, are either heavy industrial areas, large population centers or possess unique recreational features (Yaquina Bay) that are not typical of all areas of the country. The generalization of the results from these studies may therefore be somewhat questionable.

Even within this limited group there is a great variation in techniques, resulting estimates and the number of beneficial uses considered. Some of the above mentioned studies would be classified as general equilibrium studies and the remainder partial equilibrium. It is perhaps most instructive to concentrate on the partial equilibrium studies and especially those that are closely akin to possible techniques that may be adopted and utilized to acquire national water quality associated benefit and cost estimates. Two of the above studies--the Ohio and Maumee River--have therefore been selected for further consideration.

A pioneering effort to establish regional pollution abatement benefit and cost of control functions is found in H. C. Bramer's doctoral dissertation, 1960, (1). The study is a comprehensive study of the benefits and cost of pollution abatement in the Ohio River Basin considering several treatment strategies and a large number of beneficial uses. The study represents a paramount contribution to the state-of-the-knowledge in that it was completed in 1960 and is still considered to be one of the better works which undertakes the establishment of basin wide water quality associated benefits and costs. The analytical technique adopted in this study is the traditional benefit cost analysis. Both benefits and costs of pollution abatement are constructed as a function of percentage reduction in pollution load.

The pollution abatement benefit function was constructed by considering the damages and production expenses that could be avoided by numerous water-users if the pollution load were decreased. In addition other benefits such as demand shifts resulting from effluent removal were also considered, i.e., increased recreational expenditures as a result of effluent removal. In general, very little was done to include other potential benefit concepts such as latent or option demand. A complete list of the benefits considered and the dollar estimates associated with water quality improvement resulting from the inaugurative primary and secondary treatment of all emissions is presented in Exhibit II-1.

The costs of pollution abatement in Bramer's work were, as previously stated, formulated as a function of percentage reduction of pollution load, considering several treatment strategies. Exhibit II-2 from Bramer presents the above relationships based on the benefit and cost estimates derived in the study. Primary and secondary pollution abatement measures represent 40 and 85 percent reduction in effluent loads respectively. The figure is illustrative of the basic relationships and demonstrates the functional relationship between costs, benefits and degree of pollution abatement.

It is interesting to note that the costs of pollution abatement are greater than benefits derived at all points. The estimated annual benefits associated with primary and secondary abatement measures were 76.0 and 86.5 percent of the costs respectively. This is even more significant when it is realized that one benefit--recreation benefits emanating from effluent removal--accounted for approximately 78 and 74 percent of the possible cost reductions effected by primary and secondary treatment level respectively. This takes on even greater significance when it is realized that complex substitution effects were not taken into account, i.e., the recreational benefit figure derived is based solely on the

Exhibit II-1. Benefits of pollution abatement measures in the Ohio River Valley in the various uses of the surface waters

Water Use	Reductions in Costs in 1958 $	
	Primary	Secondary
Municipal Water Supplies	$ 2,657,000	$ 5,315,000
Domestic Use	6,456,000	12,912,000
Industrial Use	5,174,000	10,347,000
Thermal-electric Power	1,941,000	3,882,000
Navigation	2,300,000	4,600,000
Recreation	80,000,000	120,000,000
Hydroelectric Power	30,000	30,000
Commercial Fishing	80,000	121,000
Esthetic Enjoyment	4,300,000	4,300,000
Totals	$102,938,000	$161,507,000

Source: H. C. Bramer, The Economic Aspects of the Water Pollution Abatement Program in the Ohio River Valley, p. 134.

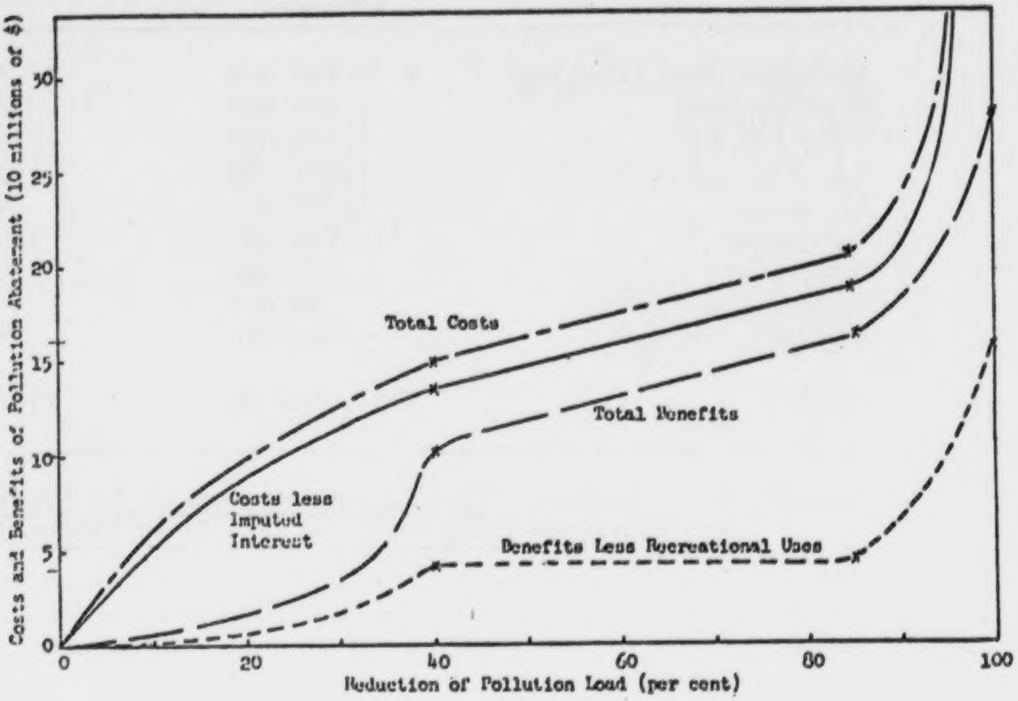


Exhibit II-2. Annual Costs and Benefits of Water Pollution Abatement Measures.

Source: H. C. Bramer, The Economic Aspects of the Water Pollution Abatement Program in the Ohio River Valley, p. 145.

increase in water based recreational activity without considering possible interaction between other nonwater based recreational expenditures. It must also be pointed out that the recreational benefits are also the most difficult to estimate due to data availability and other intangible considerations that are encountered.

A slight digression is perhaps in order at this time in that the substitution concept will reoccur at various points in later discussions. As was stated at the beginning of this chapter, the objective of environmental protection policies is to facilitate the maximization of net social welfare. The adoption of this objective dictates that the substitution phenomenon enter the analysis. The true impact of water quality degradation on recreation is not simply the total change in water based recreational expenditure in that there are many close substitutes to water based recreational activity. that also produce or yield satisfaction. As water quality deteriorates people shift out of water based recreational activities and into other recreational activities. It is the net change in recreational expenditures that must be considered. The substitution phenomenon exist for all water quality associated impacts but is considered to be most important when considering recreation benefits.

The precise results obtained if substitution effects were considered is unknown, however, the direction of change is certain. The inclusion of the substitution effect will lower--and it is further hypothesized that it will substantially lower--the above mentioned benefit estimates. As a result, the benefit cost ratio may well be substantially less than was estimated by Bramer.

An extension of Bramer's study can be found in a master's thesis by J. Matson (2). The same basic technique was applied to the Maumee River. Estimates of annual benefits and costs of pollution abatement in this sub-basin produced a benefit cost ratio of 0.96 at approximately 93 percent removal of dissolved organic matter. Exhibit II-3 presents the benefit and cost functions estimated by Matson.

It is expedient to make several observations and raise several other questions at this juncture.

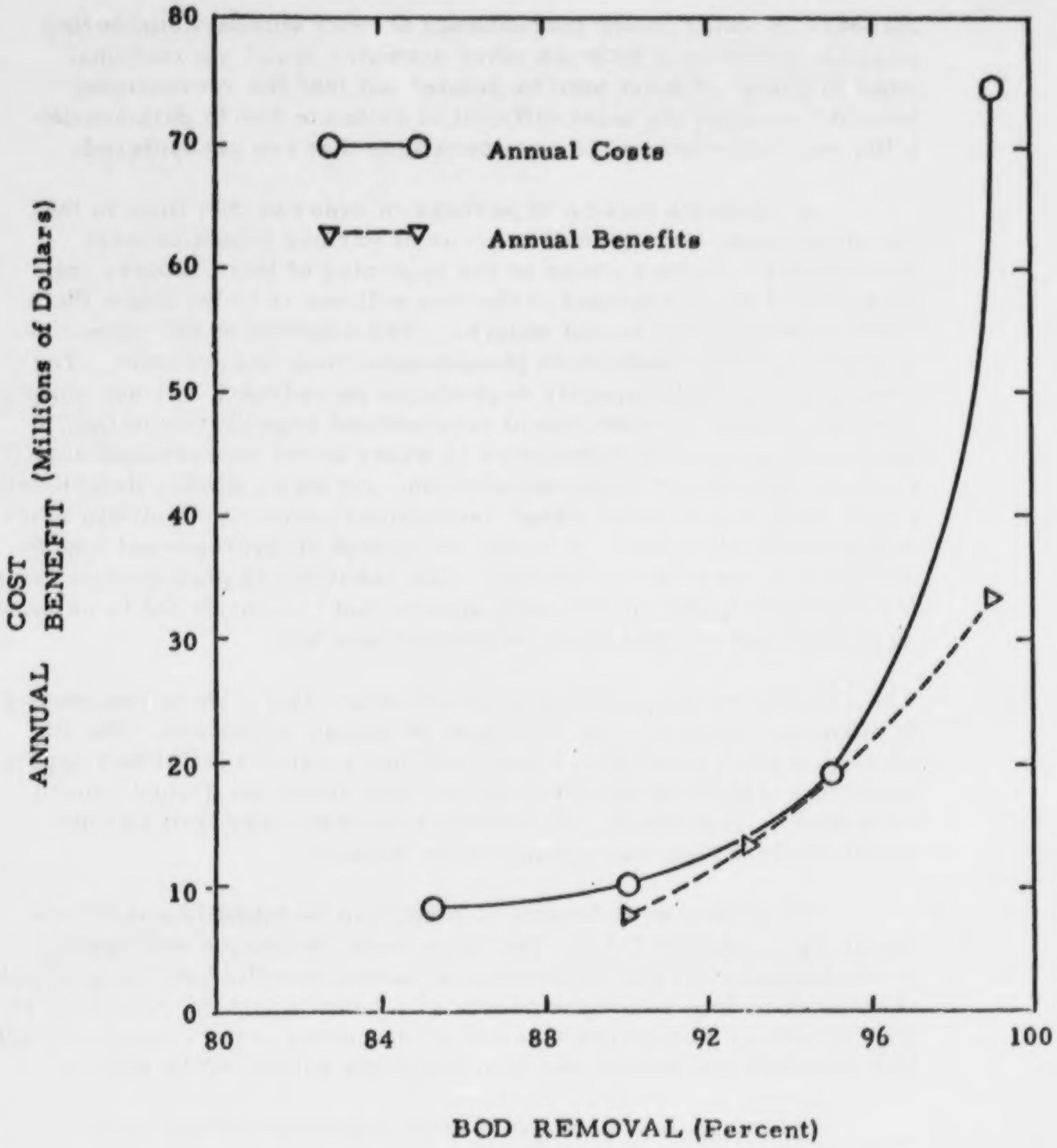


Exhibit II-3. Effect of degree of removal of dissolved organic matter from effluents on annual costs and economic benefits due to pollution abatement in the Maumee River Basin.

Source: Matson, Jack V., Cost of Industrial and Municipal Water Pollution Abatement in the Maumee River Basin, Thesis University of Toledo, January, 1968, p. 44.

1. Both studies have established the benefits and costs of pollution abatement based on numerous beneficial uses relating both benefits and costs to percentage reduction in municipal and industrial point source effluent discharges. Surface water quality resulting from pollution abatement standards depends not only on point source effluents discharge but also on assimilative capacity, area influent loads and natural and man-made non-point pollutants, i.e., a 50 percent reduction in effluent discharges does not result in a 50 percent reduction in surface water effluent loads. In other words the benefit and cost curves derived are applicable to only one point on the water quality spectrum given that all of the above factors are constant. If, however, any of the above factors change, an entirely different net benefit configuration would result if beneficial use is indeed impacted by quality of water utilized.

2. The failure to consider substitution effects reduces the credibility of resulting estimates if the objective is to ascertain the true social net benefits of pollution abatement.

3. How accurate are the data and how much reliance can be placed in water pollution abatement benefit cost ratios or functions when one single benefit component, i.e., recreational expenditures, comprises such a large percentage of the total benefits. This is especially true when the benefit is as elusive to measure as is water quality associated recreational benefits. It is not our purpose here to question the approach or the results but to merely point out that those wishing to cast doubt or discredit the results of studies similar to the above could perhaps do so with little effort. The wisdom of attempting to justify expenditures on such a vital and essential area as water pollution abatement control must therefore be grounded on a much more solid foundation.

4. The generalization of these studies to acquire national water quality associated benefit and cost functions may be questioned for a variety of reasons. First, the Ohio river basin is not representative of many of the nations surface water bodies; second, the estimation technique

> used to assess several of the benefits must be considered rough approximation only; third, a more complete assessment of non-point pollution sources and loads must be completed; fourth, the conversion from percent of treatment to resulting surface water quality must be refined; and fifth, a more complete assessment of prevailing treatment strategies and the incremental benefits and costs associated with imposition of additional treatment must be considered.

In all fairness to the above authors, it must be emphasized that their intent was to show that a substantial portion of the cost of pollution abatement is not lost but is returned to society through the benefits accrued as water quality improves. This has been accomplished in the above studies by relating benefits and costs to percent of effluent removal. It must be recognized, however, that the estimation of total net social benefits emanating from water pollution abatement is quite another matter.

It does appear that there may well be sufficient reason for opposing the extension of the above studies to acquire national water quality associated benefit and cost estimates and functions without further refinement. The above studies were tailored explicitly for a specified geographical area thereby permitting many simplifications that can not be ignored if the goal is to acquire national water quality estimates.

D. Required Extensions

One alternative in the search for national water quality associated benefit and cost estimates and functions is to utilize the same basic technique incorporated in Bramer's study but to extend and supplement the procedures to eliminate some of the basic limitations. One approach is to establish water quality associated benefits and costs as a function of water quality as opposed to percentage reduction in effluent loads. This is desirable in that the critical objective, a target variable, is water quality as opposed to reduction in effluent discharges which is meaningless without further knowledge of prevailing area water quality, relative importance of natural non-point pollutants and the resulting surface water quality. The following material will briefly discuss some of the major considerations that are required to estimate water quality associated benefits and costs as a function of water quality. The major considerations and procedures are discussed below with the details reserved for later chapters.

Costs of Pollution Abatement

The selection of appropriate pollution abatement measures must proceed on an individual treatment strategy basis. One type of treatment strategy may successfully eliminate or substantially reduce the concentration of one pollutant while it is totally ineffective in the removal of other pollutants. The cost of pollution abatement must therefore proceed on a strategy by strategy basis. For example, the use of computerized techniques have enabled the costing of 35 treatment strategies presented in Exhibit II-4. The cost of pollution abatement as a function of percent treatment (treatment strategy) is presented in Exhibit II-5, including only a representative sample of treatment strategies.

The eleven treatment strategies listed below are frequently used industrial water treatment processes. The costs of these strategies has been estimated by the Environmental Protection Agency in The Economics of Clean Water. (3)

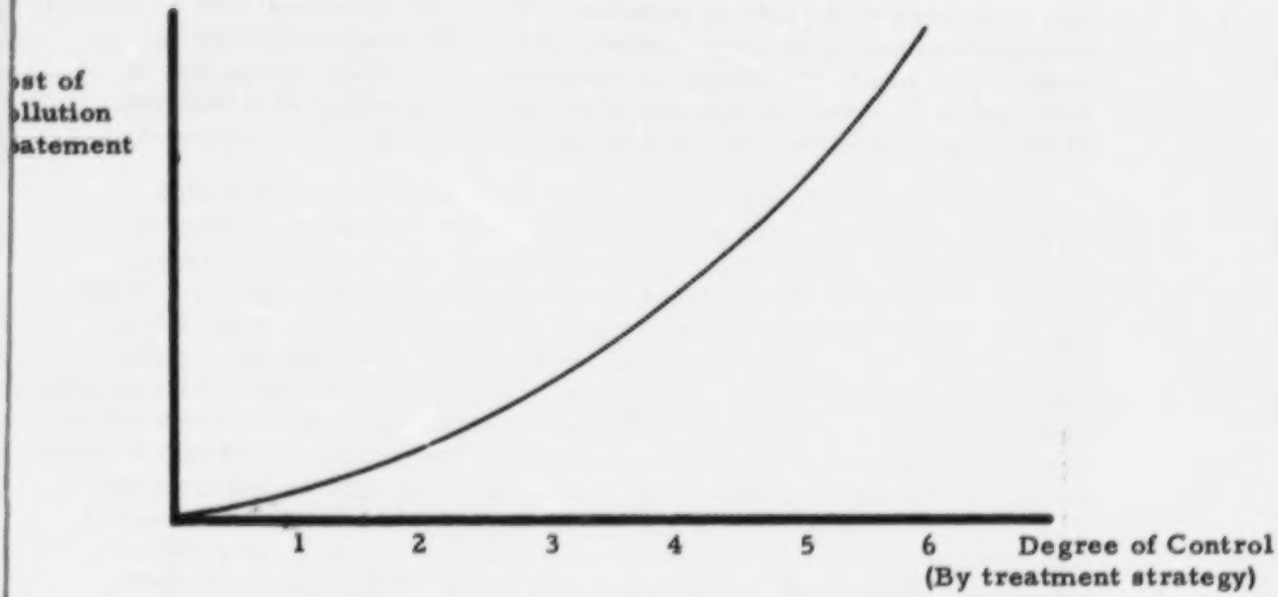
1. Oil separation
2. Equalization
3. Coagulation
4. Neutralization
5. Flotation
6. Sedimentation
7. Aeration
8. Biological stabilization
9. Chlorination
10. Evaporation
11. Incineration

Exhibit II-4. Treatment processes that can be costed by the wastewater treatment plant cost estimating program

- Raw Sewage Pumping
- Preliminary Treatment (Grit Removal, Flow Measurement)
- Preliminary Treatment (Grit Removal, Flow Measurement, Screening)
- Primary Sedimentation (Single Basin)
- Primary Sedimentation (Multiple Basin)
- Primary Sludge Pumping
- Aeration Basin Structure
- Aeration Diffused Air
- Mechanical Aeration Equipment
- Flocsillator
- Trickling Filter
- Intermediate Pumping
- Final or Intermediate Sedimentation (Single Basin)
- Final or Intermediate Sedimentation (Multiple Basin)
- Recirculation Pumping
- Stabilization Ponds
- Sludge Thickener
- Anaerobic Digestion and Building
- Aerobic Digestion
- Sludge Holding Tanks
- Vacuum Filtration (Landfill Disposal of Sludge)
- Vacuum Filtration (Incineration Disposal of Sludge)
- Centrifugation
- Sludge Drying Beds
- Sludge Lagoons
- Multiple Hearth Incineration
- Fluidized Bed Incineration
- Chlorination Building and Equipment
- Chlorination Contact Basin
- Administrative and Laboratory
- Garage and Shop
- Yardwork
- Laboratory - Activated Sludge
- Laboratory - Trickling Filter
- Laboratory - Primary Plant

Source: R. G. Eilers and Robert Smith, "Wastewater Treatment Plant Cost Estimating Program," Environmental Protection Agency, Water Quality Office, Advanced Waste Treatment Research Laboratory, Cincinnati, Ohio, April, 1971.

Exhibit II-5. Cost of treatment and degree of control (by treatment strategy).



Case 1. Primary treatment only

Case 2. Primary treatment plus secondary (biological) treatment.

Case 3. Primary treatment, secondary treatment, plus chlorination of effluent.

Case 4. Primary treatment, secondary treatment, chlorination, plus phosphate removal (lime coagulation, flocculation, settling, recarbonation and filtration).

Case 5. Primary treatment, secondary treatment, phosphate removal, chlorination, plus nitrogen removal (ammonia stripping).

Case 6. Primary treatment, secondary treatment, phosphate removal, nitrogen removal, chlorination plus activated carbon absorption.

The inclusion of a sufficiently large number of treatment processes will result in a "smooth" continuous functional relationship. Realistically, however, there would be a range of cost figures for each strategy considered because of variations in size, efficiency and a variety of spatial economic and natural conditions. The function in Exhibit II-5 would therefore depict the average cost of pollution abatement. Associated with the average cost curve would be both an upper and a lower cost boundry.

This relationship--cost by treatment strategy--must be extended to be meaningful. Water quality associated benefits are functions of priority surface water quality and must be in some way compared with costs of pollution abatement if a significant management tool is to be developed. The relationship depicted in Exhibit II-5 must, therefore, be extended. The relationship that is required is to establish the cost of pollution abatement as a function of water quality rather than degree of control or percent treatment.

Although difficult to acquire or formulate, such a transformation is essential. The above mentioned Bramer study implicitly assumes "some" unspecified relationship between treatment strategy or percent effluent removal and resulting surface water quality. Without the transformation--either implicit or explicit--it is impossible to determine the benefits to be gained from the inauguration of pollution abatement standards. The benefits in the Bramer approach are cost reductions and increased recreational water usage resulting from pollution abatement. It is therefore essential to know the relationship between various treatment strategies and resulting water quality improvement. The required relationship is not easily ascertained in that the removal of a certain percentage of effluent or pollution load by point pollution source does not result in the same percentage reduction in effluents in surface water bodies. The interaction of nonpoint pollution sources and assimilative capacity complicates the problem and requires making the relationship between percent treatment or percent effluent removal at discharge points and resulting water quality explicit rather than implicit. For example, in some basins it is not inconceivable that a 100 percent reduction in point source pollutants would result in zero benefits due to the overwhelming importance of nonpoint pollutant sources. Knowledge of the influent and effluent load, assimilative capacity, treatment efficiency and concentration and distribution of nonpoint pollution sources--both man-made and natural--is required to establish such a relationship.

The need for this required relationship has been recognized by the Environmental Protection Agency in The Economics of Clean Water as is indicated by the following material:

> The pollution source allocation is intended to produce a picture of the relative contributions of various activities that are pollution sources (note that not all activities or waste discharges necessarily result in pollution, as defined) to the situation reflected in the index. Previous efforts to establish such a ranking were hindered by a lack of correspondence of source contributions with geographically unique indicators of the resulting stream pollution and its effects. In addition to offering progress to the goal of associating discharges with pollution impacts, the present approach provides a means of unambiguously aggregating measures of source contributions to meet higher level planning information needs.(4)

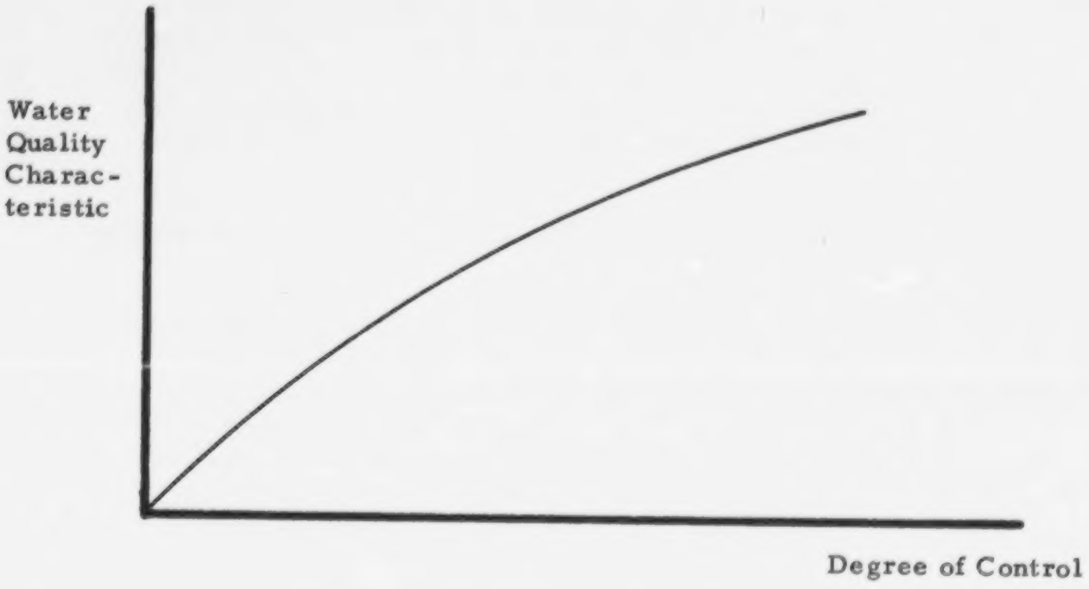
For conceptual purposes the above transformation function is hypothesized in Exhibit II-6.

It must be recognized that as the influent and effluent loads or treatment efficiencies change, the transformation function would also be altered. However, once the transformation function is established, it enables the conversion of cost of pollution abatement as a function of percent of treatment to cost of pollution abatement as a function of water quality.

Benefits of Pollution Abatement

The benefits to be derived from pollution abatement are in the realm of cost and damage reductions as well as increases in water related activities, i.e., shifting demand as a result of water quality enhancement. As water quality deteriorates, damages and costs are incurred--damages to tangible and intangible assets, reduced efficiency, additional production costs to on-going activities and reduced potential benefits emanating from foregone activities. The last economic cost of pollution is the opportunity cost associated with water quality deterioration. (The term pollution as used herein refers to the use of surface waters for waste disposal to the extent that the resulting water quality is less than natural water quality would be in the absence of such practices.) All of these economic costs must be uniquely associated with specific water quality measures.

Exhibit II-6. Water quality and percent treatment



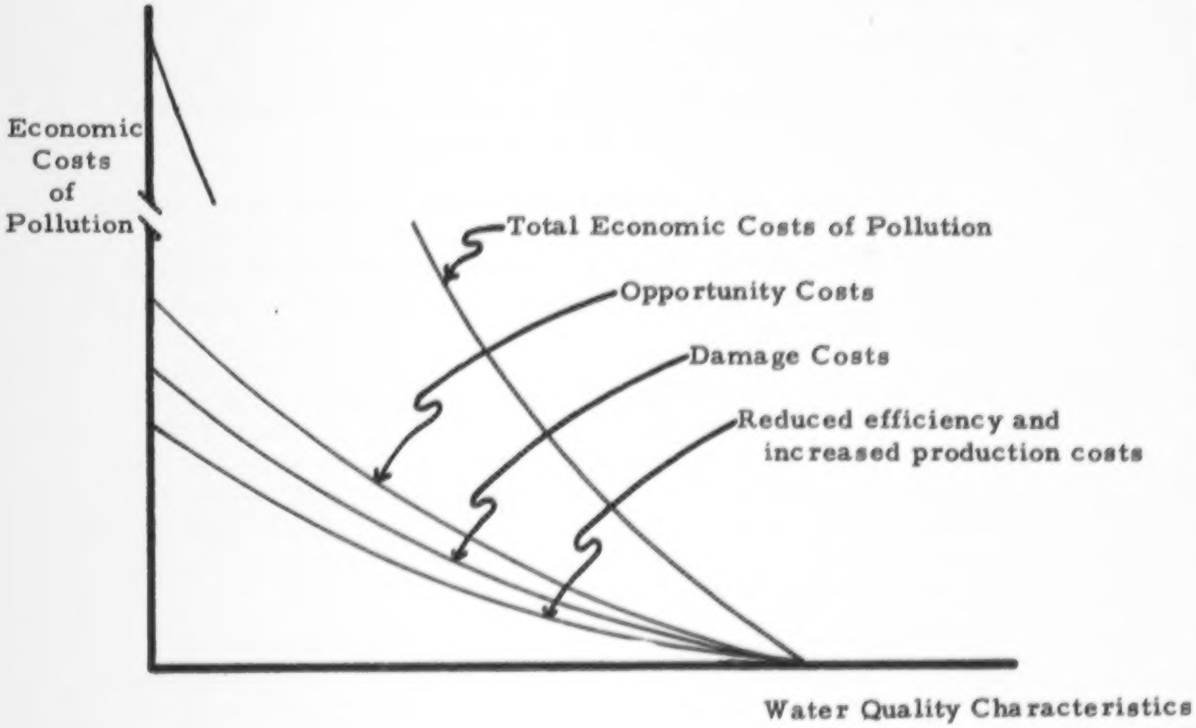
The first category--additional production costs and reduced efficiency of productive inputs--is perhaps the easiest to visualize. One of the major determinants of the value of water is its contribution as a productive input. In general this is the sole determinant of the value of water--if one includes both productive uses and non-productive uses such as esthetic appreciation. As the presence of foreign substances increase in concentration, the efficiency of the productive input is reduced. If the particular pollutant can be easily removed by conventional treatment techniques, the inherent qualities of water can be restored. If not the result is reduced efficiency of a productive input. In either case the result is the same--increased cost either because of increased preuse treatment or reduced efficiency. There is, therefore, a positive relationship between value of water in productive processes and water quality and an inverse relationship between production costs and water quality.

The same type of relationship exists between water quality and water quality induced damages. Hardness, corrosion, sedimentation and numerous other pollutants are the source of large amounts of physical damages to productive, nonproductive, natural or man-made assets.

The last pollution cost category is the opportunity cost of foregone activity as a result of water pollution. These are not damages or increased production costs to on-going activities but rather the opportunity cost of potential activities that must be foregone because of environmental degradation. These opportunity costs as well as all of the above mentioned costs also have an inverse relationship to water quality.

These relationships--economic costs of pollution--are depicted in Exhibit II-7. The abscissa of the graph is a composite water quality measure with the zero coordinate representing the area water quality that would prevail in the total absence of control. The right hand point where the total cost curve intersects the horizontal axis would represent the prevailing water quality if all pollutants other than natural pollutants were eliminated. At this point the composite economic cost of pollution curve would be zero, since by definition pollution (as defined herein) is not present. The height of the curve at any water quality to the left of the natural water quality would represent the economic costs of pollution. By considering numerous beneficial uses with varying damage thresholds the smooth curves depicted in Exhibit II-7 would result from the vertical summation of individual component cost curves.

Exhibit II-7. Economic costs of pollution


Economic
Costs
of
Pollution
Total Economic Costs of Pollution
Opportunity Costs
Damage Costs
Reduced efficiency and
increased production costs
Water Quality Characteristics

The precise relationship and magnitude of these economic costs of pollution are presently unknown but it is not unrealistic to hypothesize the relationship as portrayed.

The construction of the composite economic cost of pollution function would have to proceed on a beneficial use by specific pollutant basis for a specific geographical area recognizing the area water use and production specialties and other area and economic characteristics. As water quality is improved, the benefits derived are in the avoidance of a portion of the above mentioned costs and damages. Alternatively, if flexible abatement standards are imposed with the intent of maintaining a stable water quality over time, the economic gain is the potential damages or costs that would be avoided by further water quality degradation. The damage and cost avoidance or benefit function is depicted in Exhibit II-8.

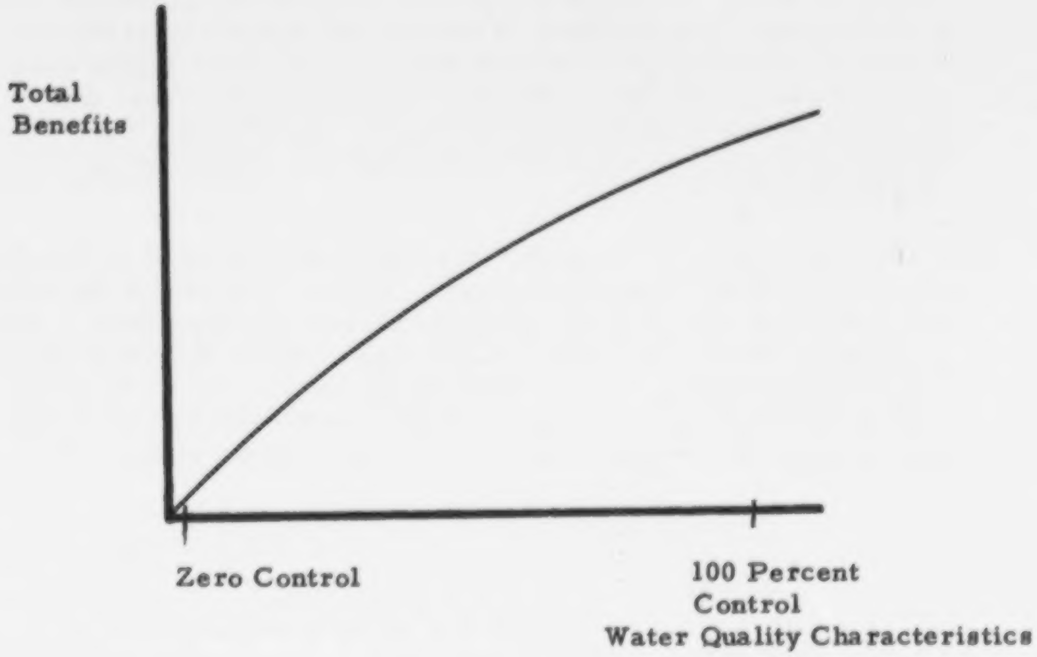
The required comparability of benefits and costs is realized--benefits (cost and damage avoidance) and cost of pollution abatement, are both a function of water quality--thereby instilling some economic meaning to otherwise sterile relationships. While the above modification and extensions have perhaps filled some of the voids in the typical benefit cost approaches to water quality management, there are several observations that are perhaps in order at this time.

1. The objective--perhaps secondary objective--of establising a method capable of ascertaining an optimal area water quality has been realized by establishing benefits and costs as a function of water quality as opposed to degree of treatment.

2. The difficulties encountered in estimating indirect, intangible benefits have not, in anyway, been diminished. Such benefits must be calculated if a benefit cost ratio close to unity is to be realized.

3. The procedure must still be applied to many individual areas due to the spatial variation of natural, physical and economic characteristics and can not be satisfactorily generalized.

Exhibit II-8. Total water quality benefits



Now that the benefit cost approach has been reviewed and refined, it is perhaps expedient to embark on a brief evaluation procedure to ascertain if the above approach will produce socially optimal results. It is useful to recall that Phase I concluded that benefit cost analysis is not an appropriate procedure to be used in evaluating the impacts of water quality degradation. This conclusion was based on a general equilibrium versus partial equilibrium approach and is forcefully conveyed by the following question:

> When a public investment program results in major structural changes in the national economy or some regional economy, and when, as a consequence, significant changes occur in the price structure, benefit cost analyses is not applicable. (5)

Given the previously emphasized point that general equilibrium analysis has not been developed to an implementational stage, partial equilibrium techniques must be utilized as a first approximation to the problem. The question that arises is that now that we have been committed to partial equilibrium analysis (duly recognizing the limitations of partial analysis), how can the problem best be formulated? Is the best framework benefit cost analysis? Is benefit cost analysis even applicable? Are there other methods that are perhaps better suited to the problem at hand?

To successfully answer these problems, a few benefit cost conventions must be recognized. The first convention is that the objective of benefit cost analysis is to assist in achieving economic efficiency or maximization of net social welfare. (6) The second convention is that the feasibility of the proposed investment be evaluated on the basis of the estimated net benefits. "The benefit cost criterion dictates that the investment program be chosen which maximizes net benefits, subject to the constraint that net benefits are positive." (7) The second convention clearly indicates that the normal usage of benefit cost analysis as described by the above references does not normally allow for the maximization of net negative benefits or minimization of net costs even in the event of investment projects involves numerous intangible and unquantifiable benefits that can not be assessed.

The question of whether actual benefits exceed cost becomes rather academic. Many contend that if all intangible benefits were accurately calculated, the benefits of water quality enhancement would greatly exceed the costs of water pollution abatement. This is purely academic in that no one has yet been able to develop a satisfactory benefit estimation technique. "While early results of recreation evaluation studies suggest that such analyses can be successfully done in certain instances and we can expect in the future they will provide us with usable damage functions, routine detailed measurement of recreational damage is not now possible." (8) Is benefit cost--given the state-of-the-arts of benefit estimation--an adequate analytical technique applicable to the task at hand? If benefit estimation is not capable of accurately assessing public preferences, then alternative techniques should be explored, and secondly to briefly hypothesize on the true social preferences. The following items and/or excerpts from summaries of previous studies shed some light on whether one can realistically expect estimated water quality associated benefits to exceed pollution abatement costs.

1. Bramer estimated a benefit cost ratio of 0.85 for the Ohio River Basin.

2. Matson estimated a benefit cost ratio of 0.96 for the Maumee River.

3. "Several studies have been models of ingenuity in using limited data and modelling or similating effects on industry operations. Some studies are available for the petroleum refining, fruit and vegetable canning, thermal power, and beet sugar industries. In all of these instances, industrial costs turn out to be surprisingly insensitive to intake water quality within comparatively wide ranges--especially in regard to aspects of quality that are usually influenced by prior uses and discharge of effluents." (9)

4. "The situation is surprisingly similar for municipal water supplies. Much of what has been said about the need for high water quality supplies as a basis for preparation of potable water is more the product of emotion than of logic." (10)

5. "Poor quality water does impose extra costs on municipal water systems but--except in cases of toxic or evil-tasting substances--use by municipalities ordinarily cannot justify high levels of waste effluent control." (11)

6. "The limited evidence from the studies and analysis discussed above leads to the virtually inescapable conclusion that high water quality must be justified primarily on aesthetic and recreational grounds, if it is to be justified at all. This conclusion is reinforced by the results of the Delaware estuary study." (12)

7. "The benefits of raw water quality improvement which could be identified as accruing to municipal and industrial water users were very small compared with the cost of improvement." (13)

8. "The annual value of the estimated loss due to shifts in the demand for angling in Yaquina Bay amounted to about $63,000. This is less than the capital cost (but excluding annual operating costs) of a basic sewage treatment plant for a comparatively small city." (14)

9. Preliminary estimates of water quality associated health impacts suggests that an annual rate of only 1.1 water borne illnesses per 100,000 population can be directly attributed to surface water quality degradation. (15)

10. Viral infectious hepatitis can be transmitted by water routes, although this is rare. (16)

11. Several studies indicate that untreated groundwater and not surface water has been the most frequent cause of recent gastro-enteritis and diarrhea and not surface water degradation. (17)

12. Preliminary estimates of domestic damages resulting from water of questionable quality indicates that the private wells are the major source of such damages. A large portion of the remainder of the damages that are attributable to surface water impairment are the result of hardness and mineralization that are present in varying degrees in water in its native state. Removal of such pollutants would require extensive and perhaps unreasonable treatment costs.

13. Most of the previous studies have been in areas that can not be considered typical of the nation as a whole such as the Delaware estuary, Potomac River, Ohio River or the Miami Basin which are highly industralized or population centers that already face severe water quality problems. These area studies result in significant benefit estimates.

14. Very few if any of the above studies have considered substitution effects which would further reduce the national water quality associated benefits. (On the other hand, neither have most studies considered all types of benefits expected.)

The above items and excerpts indicate that health, production, and municipal users can not be considered to be the source of large benefits of water quality improvement. It therefore appears that the only way pollution abatement measures can be justified in a benefit cost framework is through the accurate assessment of recreation and esthetic benefits--which is not possible at the present time. The use of benefit cost analysis as a water quality management tool can not, on the basis of the above excerpts, be expected to result in positive national net benefits for the following reasons:

1. Inability to accurately measure and assess intangible and indirect benefits.

2. Other least cost techniques such as preuse chlorination effectively reduce many of the adverse water quality associated impacts.

3. Consideration of substitution effects will substantially reduce a significant portion of the total water quality associated impacts.

4. The benefits, as normally defined, are not of the magnitude as frequently hypothesized.

The question that arises is in reference to how the true social objectives can best be served. If the public decision would be to inaugurate pollution abatement investment even if the benefit cost ratio is less than unity then we can conclude that benefit cost analysis is not appropriate perhaps for the reason that we can not accurately assess or assign values to intangible benefits and public preferences in general. (18) Why then must the water quality management problem be cast in a benefit cost framework and is there an alternative that circumvents the undesirable features of this type of analysis? In addition, there may be other reasons why alternative methods may be preferred.

E. An Alternative Approach

By couching the water quality management in an alternative conceptual framework, some of the difficulties can be avoided. This setting is a cost minimization approach where costs include both treatment costs and damage costs, e.g., damages, efficiency costs and opportunity costs. This is desirable for several reasons some of which are listed below:

1. As is stated in Managing Water Quality: Economics, Technology, Institutions by Kneese and Bower, "cost minimization ... calls attention to the fact that water quality management is essentially a matter of cost avoidance."

2. It also calls attention to and assists in deriving an optimum result in that it minimizes the overall costs associated with waste disposal activity.

3. Since the primary source of the pollution problem stems from externalities or avoidance of on-site costs, the proper approach is to consider and minimize all costs (both on-site and off-site costs). This is a significant step in the internalization of external costs.

4. Certain natural resources are considered common property resources belonging to the society in general. The use of these resources as disposal system results in a cost savings to producers but more importantly a value reduction or a cost to society in general. There seems to be a basic inconsistency or incongruency associated with inflicting damage to a publicly owned common property resource and subsequently calling the

results of corrective measures a social benefit and further basing the feasibility of these corrective measures on highly questionable benefit estimates. This benefit misnomer and the resulting temptation of using a highly structured benefit cost framework which may not be capable of producing socially optimal results is eliminated by adopting a cost minimization approach.

5. The use of benefit cost analysis inevitably results in comparing derived water quality associated benefit cost ratio with benefit cost ratios derived for other proposed public investment projects. In view of the fact that an accurate assessment of water quality associated benefits can not be achieved at the present time and the public desires pollution abatement measures this may not be desirable in that it is quite likely that the derived water quality associated benefit cost ratios will be relatively low and may never be of sufficient relative magnitude to justify additional pollution abatement investment. It is therefore desirable to disassociate pollution abatement programs from other possible public investment projects by recognizing the fact that pollution abatement programs are necessary and seek out least cost methods of minimizing the total costs of waste disposal associated with producing a given quantity of goods.

6. The last point--while very subjective and opinionated--is that there may be less reluctance to include estimates of intangible and somewhat uncertain pollution impacts in a least cost framework than in the standard benefit cost framework.

In summary, the above items indicate some advantages to be gained by formulating the problem in a cost minimization framework. This framework is easier to conceptualize and therefore has considerable merit. If the public desires pollution abatement measures even at some material sacrifice let us recognize this desire and formulate the problem so as to minimize the problem of total waste disposal.

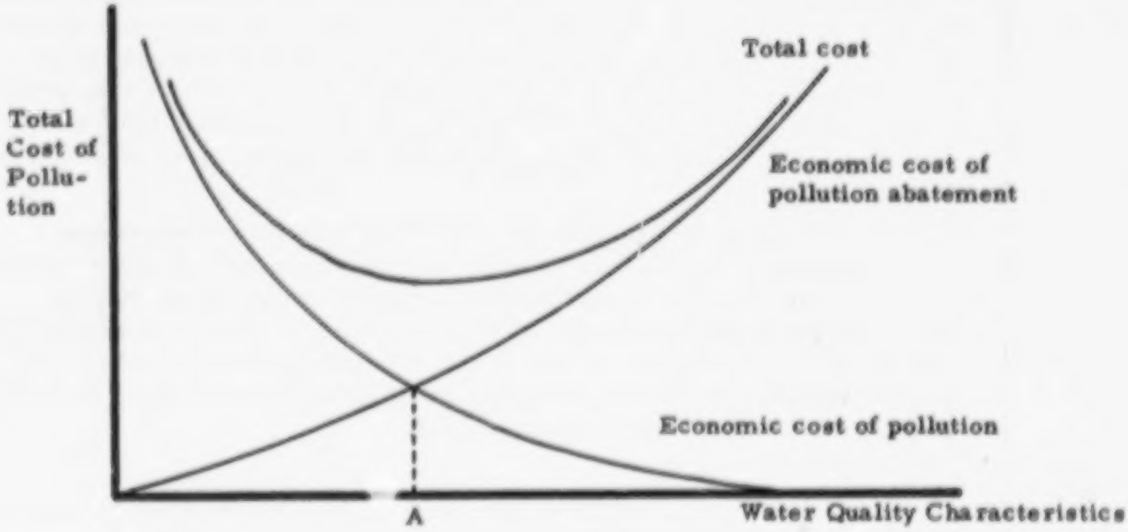
The construction of the total cost of pollution function must consider both on-site and off-site disposal costs. The off-site (economic costs of pollution) costs are the economic costs of pollution that vary inversely with the level of water quality. In the total absence of control, the economic costs of pollution are at a maximum and alternatively at the level of total control, the economic costs of pollution are zero as portrayed earlier in Exhibit II-7. The second component of total social cost of pollution is the cost of pollution abatement as presented earlier in Exhibit II-5. These components and the corresponding total cost curve are depicted in Exhibit II-8. The social objective can be maximized by selecting the water quality level which minimizes the total waste disposal cost such as point A in Exhibit II-9.

The expressed preference for the cost minimization approach places the problem in its proper conceptual setting but does not in any way complicate or add to the required estimation problems. The economic cost of pollution must be established in both the cost minimization and the benefit cost framework. The costs of pollution abatement must also be established regardless of the analytical framework. The transformation function relating degree of treatment and resulting water quality must be considered in both procedures. The only difference is in the way one views and interprets the final results. Since the cost minimization procedure is preferred, the terminology from this point on will reflect this preference (the benefit associated with water quality enhancement are properly referred to as reductions in the economic costs of pollution).

Before proceeding to the following chapters it must again be emphasized that as long as only partial estimates of the economic cost of pollution are available any analytical framework will be deficient in deriving socially optimum results. The framework that approaches the problem in the most straight-forward manner consistent with the nature of the problem is desired however. In this regard cost minimization is preferred.

The following sections are devoted to a further discussion of the estimation procedures and techniques that are required to establish the above cost curves. Since the estimation procedures are essentially the same as would be required in a benefit cost framework, Sections III and IV are rather brief and general. Section V does, however, discuss at some length required extensions that have not been as of this time presented in water quality management literature.

Exhibit II-9. Total cost of waste disposal.



Footnotes

(1) Bramer, H. C., "*The Economic Aspects of the Water Pollution Abatement Program in the Ohio River Valley,*" Doctoral Dissertation, University of Pittsburg, 1960.

(2) Matson, J., *Cost of Industrial and Municipal Water Pollution Abatement in the Maumee River Basin,* Master's Thesis, University of Toledo, 1968.

(3) Environmental Protection Agency, "The Economics of Clean Water,", 1972.

(4) *Ibid.*, Environmental Protection Agency, 1972.

(5) Lind, R. C., "Benefit-Cost Analysis: A Criterion for Social Investment," Campbell and Sylvester (eds.) *Water Resources Management and Public Policy*, University of Washington Press, 1968.

(6) *Ibid.*, R. C. Lind

(7) *Ibid.*, R. C. Lind

(8) Kneese, A. V. and B. T. Bower, Managing Water Quality: Economics, Technology, Institutions, *Resources for the Future*, John Hopkins Press, 1968.

(9) *Ibid.*, Kneese and Bower.

(10) *Ibid.*, Kneese and Bower.

(11) *Ibid.*, Kneese and Bower.

(12) *Ibid.*, Kneese and Bower.

(13) *Ibid.*, Kneese and Bower.

(14) *Ibid.*, Kneese and Bower.

(15) Weibel, S. R., et al., Water Borne--Disease Outbreaks, 1946-1960, *Journal of the American Water Works Association*, 1964.

(16) Wenk, V. D., A Technology Assessment Methodology, Water Pollution: Domestic Wastes, The Mitre Corporation, 1971.

(17) Ibid., Wenk.

(18) We feel that there is substantial evidence which indicates that the public indeed desires increased environmental protection and is willing to perhaps make some material sacrifices to achieve this end. If the state of the knowledge can not accurately measure this public desire and the public is willing to make a material sacrifice then it is a mistake to utilize benefit cost analysis as a decision making criterion.

(19) Op. cit., Kneese and Bower.

SECTION III

ECONOMIC COST OF POLLUTION

A. Multidimensionality

The successful estimation of the composite economic cost of pollution function that was discussed in the previous chapter can be achieved only by disaggregating the problem into manageable segments. The multidimensionality of the problem prohibits tackling the problem in its entirety without further simplification. The composite function can be constructed only by considering the individual components. In effect this requires disaggregation on at least three levels, i.e., specific beneficial uses, specific pollutants and a geographical delineation. The purpose herein is to briefly consider the characteristics of the individual economic cost of pollution components, and secondly, to elaborate on the procedure required to estimate individual pollution costs and finally to further discuss a meaningful aggregation scheme so that the desired national estimates can be derived, i.e., aggregation of individual benefits to derive composite area costs of pollution functions and aggregation of composite area costs of pollution functions to achieve national estimates and functions.

B. Beneficial Use Classification

The cost of pollution is incurred or borne by a variety of water users--including both tangible and intangible water uses. The economic costs of pollution are therefore the damages, efficiency reductions, process changes, additional expenses incurred and the opportunity costs that are imposed on a variety of beneficial uses. The most logical method of assessing the economic costs of pollution is therefore to consider each of these uses to estimate the economic cost of water quality degradation by user.

A variety of taxonomies have been used in delineating uses with each scheme tailored to best serve and facilitate the immediate objectives at hand. The scheme adopted in the state-of-the-art review considered four broad beneficial use areas--health, production, esthetics and ecology. While this scheme does not succeed in establishing completely unique categories totally absent of interdependence, it does successfully isolate major beneficial uses under separate headings or divisions. Health includes all human health water quality associated impacts. Production includes all industrial, municipal and domestic water usage. Esthetics includes all esthetic considerations that are directly or indirectly associated with water usage while ecological considerations include all natural water uses that directly or indirectly effect a variety of natural (ecosystem) functions. Each of these broad groupings can be further divided into many subdivisions. Exhibit III-1 presents a representative listing of beneficial uses and the water quality impacts that can be associated with each beneficial use.

Each of these beneficial uses depend on and use water in a variety of specialized ways and only by considering the detrimental impacts of increased pollutant concentrations on each of these uses can the true social cost of water quality degradation be ascertained.

C. Economic Costs of Pollution

A delineation of beneficial uses is only the starting point in that the costs of pollution to each use may consist of various types of costs. These costs may take the form of damages to natural or man-made assets, increased production expenses, reduced efficiency or increases in opportunity costs. Only by considering all of the costs of pollution can the true economic cost of water quality degradation be ascertained. A brief description of the various types of damages are listed and briefly described in Exhibit III-2.

Since the economic costs of pollution are dependent on beneficial use, an aggregate water quality measure is meaningless in that use is specialized and the cost of pollution incurred emanates from the presence of specific undesirable water quality constituents, i.e., the presence of toxic substances significantly impairs the value of water used for human consumption but has no conceivable effect on other water uses such as the production of primary metals. The potential gain to be realized from belaboring the argument beyond this point is minimal so in summary it is sufficient to conclude that the cost of pollution function must by necessity be constructed by considering numerous uses, various costs and a variety of specific pollutants. By considering the costs of pollution by specific pollutants and beneficial uses, the most damaging pollutants can be isolated and this in turn is expected to provide further insight into possible

Exhibit III-1. Beneficial use classifications and specific impacts of water pollution

Use Classification	Specific Impact
I. Health	All water quality related diseases. For a listing of water related diseases refer to Table I of health section, Appendix B.
II. Production	
A. Municipal water use	Increased preuse treatment cost as a result of water quality deterioration, i.e., additional expenditure for softening, iron and manganese removal, chlorination, corrosion control, taste and odor control, and filtration above and beyond what would be required to utilize water in its natural state.
B. Domestic water use	Increased use of water softeners, detergents, soaps, increased plumbing costs (pipes, water heaters, etc.) and increased use of bottled water for drinking purposes.
C. Industrial water use including the following industrial groups: Food and Kindred Products Textile Mill Products Lumber Paper Chemicals Petroleum and Coal Rubber Leather Stone, Clay and Glass Primary Metals Electrical Equipment Transportation Equipment	Softening, iron and manganese removal, chlorination, taste and odor control, and filtration. Reduced heat transfer rates because of scaling and fouling of heat transfer surfaces and reduced equipment life because of corrosion, and other undesirable impacts stemming from excessive effluent loads.

Exhibit III-1 (continued)

Use Classification	Specific Impact
D. Commercial fishing	Decreased fish yield and increased production costs as a result of water quality degradation. Increased maintenance and repair costs of commercial vessels and supporting equipment.
E. Agricultural water use (1) Animal production	Increased animal production costs as a result of contaminated food supplies, death and alteration of psychological function, reduced daily gains and increased cost of health control measures.
(2) Plant production	Increased production costs due to crop failures, yield restrictions or marketing constraints as a result of increased man-made effluent loads.
F. Navigation water use	Excessive corrosion and maintenance on all water craft. Channel maintenance, dredging and acid mine damage to navigational support equipment resulting from excessive effluent flows.
G. Thermal-electric and hydro-electric power generation water use	Increased repair maintenance and damages to power generation equipment, reservoirs and dams as a result of increased effluent loads.
H. Federal installation	Impact for federal installation include increased preuse treatment and increased physical damages resulting from use of water possessing undesirable constituents.
I. Transportation	Impact for transportation include reduced efficiency, damage to equipment and increased preuse treatment directly related to man-made pollutants.

Exhibit III-1 (continued)

Use Classification	Specific Impact
J. Other production	Other damages, reduced efficiency and additional expenses incurred to other production processes not specifically mentioned above.
III. Esthetic	Reduced esthetic appreciation, property value reductions and reduced potential for travel and reductions in water based recreational activities and expenditures as a result of reduced human esthetic appreciation resulting from undesirable water quality constituents.
IV. Ecological	The disruptions of vital life support cycles and systems resulting in unknown and unpredictable social, economic and ecological consequences.

Exhibit III-2. Economic costs of pollution

Type	Description and Illustration
Damages	Physical damages and reduced value of resources as a result of undesirable water quality constituents. This includes many types of damages to a large number of resources, i.e., both natural and man-made, which are directly or indirectly effected by man-made pollutants.
Increased Production Expenses and/or Reduced Efficiency	Many types of preuse production expenses and/or process changes necessitated by water quality degradation are illustrative of this impact. In addition, there are some water quality variables that cannot be removed by conventional treatment strategies or are present in only minor concentrations that are not treated but still impair the value of water to some degree by reducing the efficiency of water as a productive input.
Environmental Risk	An indirect, and often times intangible, cost of pollution stems from the uncertainty of damages which might occur following environmental degradation. Costs of avoidance of environmental risk and precautionary measures are thus economic costs of pollution.
Opportunity Costs	In addition to the above damages, increased production expenses, efficiency reductions and risks there are other economic costs of pollution. These take the form of opportunities lost or inability to utilize, develop or appreciate various natural resources. This loss or perhaps potential loss is the part of the opportunity cost of pollution. This category is net of the other above mentioned economic costs. It further includes the option and latent demand concepts.

pollution abatement strategies by isolating the major sources and further dictates the treatment strategy required. Appendix C presents a variety of important pollutants and groups of pollutants, the major source of these pollutants, possible damages incurred from excessive concentrations and treatment required to eliminate these pollutants.

The complication that is encountered is that each use may realistically be dependent on several water quality variables. For example, water used for contact recreation purposes should meet several quality requirements--fecal coliform, temperature clarity, floatable oil, suspended solids and odor requirements. For this reason multivariate functions may have to be developed or alternatively simplified function relating economic cost of pollution to selected key variables may be used as a first approximation of the functional relationships between cost of pollution and water quality. Significant inroads have been made in the area of relating water use requirements to key water quality variables. A variety of well established critical levels and damage thresholds have been established and are presented in Appendix D for selected water uses. These critical levels and damage thresholds will have to be considered in assessing water quality associated impacts in that exceeding the critical level or damage threshold will result in increased costs, increased damages or perhaps complete elimination of the beneficial use.

Estimation Procedure

The above mentioned multidimensionality, variations in data availability and data form and variations in functional form of the hypothesized relationships prohibits prescribing a single technique applicable to the estimation of all economic costs of pollution. The estimation procedure must be tailored to the specific characteristics of individual water quality associated impacts. The procedure required, regardless of the type of analysis, or irrespective of the beneficial use under consideration is to ascertain the additional cost incurred as a result of water quality degradation. In many cases this will, in effect, require a complete analysis of the cost determinants or independent variables affecting water using activities at several water quality levels. Only by observing costs and participation rates at several water quality levels can the economic costs of pollution abatement be ascertained. "Before and after" examples incorporating demand analysis, regression analysis, option demand, participation rates, percentage reductions and cost variations are relevant methods, techniques and concepts useful in assessing the economic costs of pollution. The most descriptive method of portraying such cost estimation procedures is to do so by using several illustrative examples that have been used in previous attempts to quantify the economic costs of pollution. The basic goal of all of these techniques is to delineate the independent variables affecting water usage so as to allocate the portion of total costs that can be correctly associated with water quality degradation. It would be desirable to delve into specific techniques that might be utilized in Phase III, but until specific areas of further study have been selected, it is not desirable to devote a large amount of effort to such tasks. The following discussion is therefore rather general and is valuable for illustrative purposes only.

Costs of Pollution and Municipal Preuse Water Treatment Costs

The cost of preuse municipal water treatment is determined by numerous physical and economic spatially dependent variables. The important municipal preuse treatment independent cost variables are listed below:

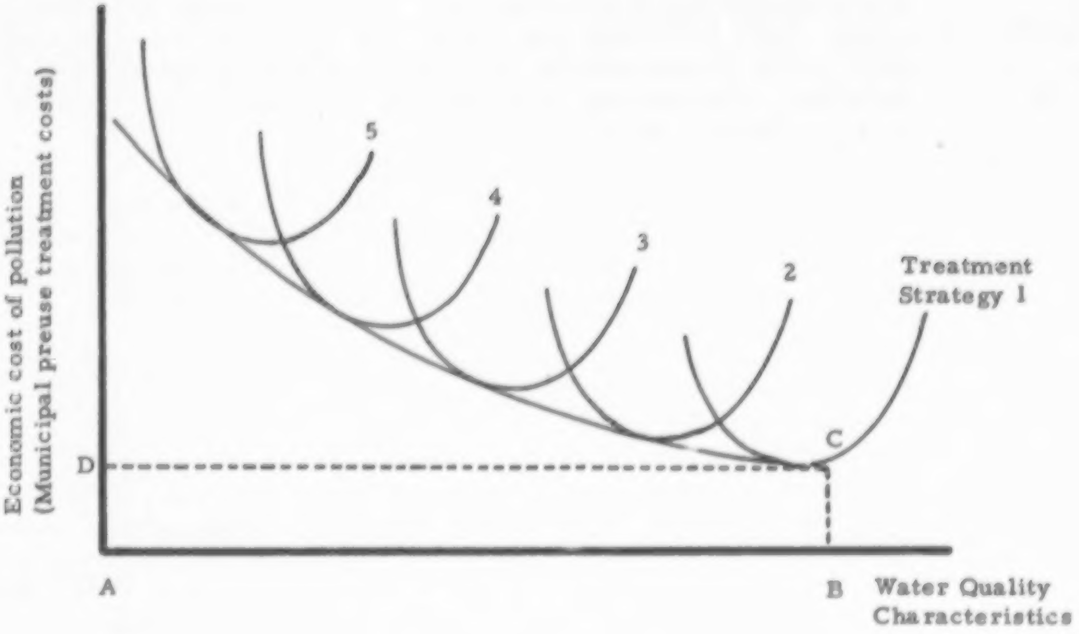
1. Prevailing treatment strategy
2. Capacity of the system
3. Utilization of the system
4. Ownership of the system
5. Regional wage rates
6. Age of the institutions
7. Cost of variable inputs
8. Concentration and type of effluents

Municipal preuse water treatment costs should involve allowances for both man-made point source emissions and natural pollutants which are present in prevailing water sources. The appropriate treatment strategy and the consequent cost of pollution attributable to man-made sources may be derived from a total cost of treatment relationship as follows. Given the prevailing regional wage rates and the other appropriate spatially dependent exogenous variables, the cost of preuse municipal treatment strategies in the absence of manmade pollutants can be ascertained. Incremental municipal preuse treatment costs that are incurred as a result of increased effluent loads can justifiably be classified as the economic costs of pollution. These may take the form of increased operation and maintenance costs as a result of increased effluent loads or increased capital costs associated with more advanced and sophisticated treatment strategies necessitated by the introduction of manmade pollutants.

The preuse municipal average cost curve for a given area is the envelop curve associated with a variety of constituent individual cost curves each applicable to specific treatment strategies required to reduce effluent loads associated with specific water qualities. The envelop curve and the constituent curves are depicted in Exhibit III-3.

Several observations are in order at this juncture. At some point in the above hypothesized relationship, the cost of preuse municipal treatment would reach a minimum, indicating that some preuse treatment costs would be incurred regardless of the prevailing water quality. Chlorination, filtration and other treatment processes are essential irrespective of the prevailing water quality. The reason for this distinction is that the economic cost of pollution is represented by the portion of the curve above and to the left of the minimum cost point. For example, if the water quality free of man-made pollutants is determined to be water quality B in Exhibit III-3, the true cost of pollution is the height of the curve at every point less the quantity BC. The cost of municipal preuse treatment curve can therefore be converted to an economic cost of pollution curve simply by shifting the ordinate upward by a distance equal to the cost of preuse municipal treatment in the absence of man-made pollutants such as point D in Exhibit III-3.

Exhibit III-3. Economic cost of pollution in reference to municipal preuse treatment.



The estimation of the entire function would be desirable but time consuming task. The required level of effort can be substantially reduced by considering only two points, one, the cost of treatment associated with the prevailing water quality and the second is the costs associated with treating water in its natural state. For a first approximation, such simplifications are not unrealistic. The above endeavors are not unrealistic in that cost data for municipal preuse treatment plants are quite accessible. Essentially what has been described is a "before and after" example with the difference being attributed to increased effluent loads and lower quality of surface water withdrawn.

Estimating Recreation Impacts of Water Quality Degradation

Other estimates of the economic costs of pollution are also available in the literature. Few, however, are as straightforward as the above municipal preuse treatment example. One example of an attempt to estimate the recreation impacts of pollution is presented in the well publicized Delaware Estuary Study. (1) The estimation procedure incorporated multivariate regression analysis to isolate the critical variables influencing participation in water based recreational activities. Exhibit III-4 presents the socioeconomic and locational variables that were used to determine the important independent factors influencing participation rates in various water based recreational activities.

From this information recreational probability of participation equations were formulated. Once the equations were established appropriate values of the relevant exogenous variables were computed and applied to determine the corresponding value of the dependent variable. This in effect establishes total participants prior to water quality improvement for the benefit considered. The next step was to assume that some water quality improvement would subsequently enhance the rating of fishing facilities (FPS) from previous levels to higher levels. With the improvement in the FPS new probability and usage functions were developed. A comparison of the usage rates with quality improvement with the previous unimproved usage rates revealed that a significant increase in usage results from water quality improvement. This difference is the cost of increased effluent loads. This represents another method of establishing the costs of pollution--economic costs in the sense of opportunity costs of foregone usag There are numerous other examples of previous

Exhibit III-4. Recreation participation variables.

Variable	Symbol	Description
Age	A	discrete midpoint values of class intervals
Income	Y	discrete midpoint values of class intervals
Sex	S	0 if female 1 if male
Education	E	1 if grade school highest attainment 2 if high school highest attainment 3 if college highest attainment
Race	R	0 if non-white 1 if white
Life cycle	L_1	0 if no children in household 1 if children in household
	L_2	0 if no children over 5 years old 1 if children over 5 years old
Urbanization (belt)	U	0 if urban location 1 if suburban or outlying location
Occupation	O	0 if blue collar 1 if white collar
Region	G	0 if Northeast or North Central 1 if West or South
Participates in fishing	FP	0 if non-participant 1 if participant
Participates in swimming	SP	0 if non-participant 1 if participant
Participates in boating	BP	0 if non-participant 1 if participant
Water per capita	W	area of sport fishing water per capita by state, 1960
Expert rating of swimming facilities in primary sampling unit	SPS	discrete values of 1 through 5
Expert rating of fishing facilities in primary sampling unit	FPS	discrete values of 1 through 5
Coastal area presence	C	0 inland area 1 coastline or Great Lakes present

Source: Allen V. Kneese and Stephen C. Smith, (ed.), Water Research, p. 193.

attempts to establish the cost of pollution as a function of water quality. These include establishing soap and detergent purchases, crop yields, property value charges, maintenance costs, domestic damages, and other damages to appropriate water quality levels. Each attempt must essentially isolate and determine the important cost and usage independent variables and assess the portion of the total that can be attributed to increased effluent loads. As was initially stated at the beginning of this chapter, the precise technique and analytical procedures incorporated must be tailored to the specific use under consideration. One additional illustration of estimating procedure and consideration involved in estimating health impacts is presented in the health section in Appendix D.

D. Aggregation

The problem of aggregation is intrinsic to the construction of national pollution cost estimates. There are several levels at which the problem is encountered. First, individual beneficial use pollution functions are established and must be aggregated to achieve composite area economic cost of pollution functions. Since the ordinate or y axis is dollars per unit of water used, dollars per capita or cost per shoreline mile which can be easily aggregated into meaningful regional totals if a composite multivariate measure is depicted on the abscissa.

The second level of aggregation, i.e., region by region aggregation of composite functions, must proceed on the same general basis. The many complications and complexities that are likely to be encountered in aggregation are recognized but not developed at this point. A more effective place and time for such a discussion would be after regional cost estimates have been established and a better appreciation and understanding of the aggregation problem is achieved.

E. Summary

Many attempts to estimate the economic costs of pollution to specific beneficial uses are present in the literature.

Each method must be sensitive to the specific characteristics of the beneficial use under consideration. The estimation of the national costs associated with pollution must therefore seek out specific examples and data sources which facilitate and expedite the analysis. Extreme care must be taken in extending regional estimates to national estimates in view of the many and diversified regional water use characteristics and water quality requirements.

Footnotes

(1) **Kneese, A. V. and Stephen (ed.) Water Research, Resources for the Future, Inc., John Hopkins Press.**

SECTION IV

COST OF POLLUTION ABATEMENT

A. Introduction

Estimating national pollution abatement costs has progressed to an advanced state relative to the establishment of national benefit functions. The methodology is well established and little change is needed. There is, however, substantial need to further extend the analysis to adequately portray the relationship between pollution abatement measures and resulting surface water quality. This extension is the subject of Section V and will not be discussed here. In an attempt to be complete this brief chapter concerning the cost of pollution abatement has been included. We shall first discuss the procedures utilized to establish the cost of pollution abatement function and secondly, briefly summarize some of the material from Appendix A.

B. Procedures

The general method of establishing national or regional pollution abatement functions must proceed by considering individual treatment strategies by pollution source. A listing of possible strategies was presented in Section II. Unfortunately it is not possible at the present time to consider or establish a national pollution abatement function considering all of the treatment strategies listed. The alternative is to establish the cost function by constructing the cost of a few strategies assuming that all pollution sources within the region or country adopted a given strategy. This procedure is the technique most frequently used in the partial equilibrium studies reviewed. Assuming varying treatment strategies presents significant data and estimation problems with respect to both costs and resulting water quality and will not be pursued further at this point in that this constitutes a long run objective. The simplifying assumption that all pollution sources within a given basin adopt standard abatement measures is realistic in that isolated controls can not be expected to significantly reduce the total effluent load. This assumption was adopted by Bramer and justified on the following basis:

> This type of isolated pollution abatement results in the correction of local nuisance problems, but does not improve water quality so as to permit well-rounded water uses. This was the basis upon which the State of Ohio exempted its municipalities on the Ohio River from requirements of the installation of waste treatment facilities until those upstream in other states took action. It is on the same basis that Pennsylvania has not required treatment facilities on streams subject to acid mine drainage until a satisfactory solution to this problem is found. (1)

By adopting similar assumptions and limiting the number of possible treatment strategies under consideration, the establishment of regional or national pollution abatement functions would be a relatively routine task. Even though it would be a routine task it would require an enormous amount of data collection. A similar task--involving a complete assessment of present and projected industrial waste treatment strategies--has been recently published by the Environmental Protection Agency.

In that it has been constantly emphasized throughout this report that the establishment of cost of pollution abatement functions does not represent the area of greatest need, we will not belabor the point further but will briefly recognize several limitations that currently exist.

C. Limiting Factors

One major limitation is that given present state of the knowledge constraints, it is difficult, if not impossible, to incorporate nonpoint pollution costs into such a framework, not because the framework is deficient but because estimates of nonpoint pollution load and treatment costs have not been adequately developed. It is also impossible to relate cost of pollution abatement to national water quality in that a meaningful national water quality estimate is not available and is not meaningful due to the disparity of water quality levels. This further reinforces previous conclusions that cost estimates are meaningful only in reference to small hydrological areas in that present aggregation methods have not been adequately refined.

The current state of the knowledge with respect to pollution abatement costs can best be illustrated by summarizing some of the information presented in Appendix A.

D. National Pollution Abatement Cost Estimates

From the material presented in Appendix A it is possible, with only a few extensions, to develop national pollution abatement cost estimates. The estimates that are developed can not be related to water quality levels or a variety of treatment strategies but instead portray the cost of pollution abatement required to meet current standards. Industrial pollution abatement cost estimates use in Appendix A are based on estimates provided in the Economics of Clean Water which estimates the industrial cost of achieving the equivalent of secondary treatment as indicated by the following excerpt from the same publication.

> What is the cost of wastewater treatment to U.S. industry assuming that industry must reach the equivalent of secondary wastewater treatment as stated in the Water Pollution Control Act. (2)

Adopting the same assumptions for municipal treatment costs, i.e., assuming all municipalities achieved the equivalent of secondary treatment, produced the total cost figures as presented in Exhibit IV-1. From the material in Exhibit IV-1 it is possible to develop a preliminary national cost function relating costs of pollution abatement to the prevailing water standards.

Municipal and industrial water treatment cost for secondary treatment on an annualized basis would be 3,880 and 4,562 million for 1968 and 1976 respectively. The question that immediately comes to mind is how do these figures compare with the possible economic cost reductions that might be realized. Unfortunately, this can not be determined without first ascertaining the water quality improvement that would be realized if the equivalent of secondary treatment were inaugurated. This general topic is further discussed in Chapter V.

Exhibit IV-1. Total capital, operating and maintenance costs required to meet current standards in 1968 and 1976 (1967 dollars expressed in millions)

	1968 Required capital	1968 Operating and maintenance	1968 Total annualized costs */	1976 Required capital	1976 Operating and maintenance **/	1976 Total annualized costs */
Municipal	16,810	731		19,382	843	
Industrial	8,966	1,320		10,752	1,582	
Total	25,776	2,051	3,880	30,134	2,425	4,562

---

*/ All capital costs were annualized on the basis of 25 years and 5 percent interest.

**/ The 1976 operating and maintenance figures were derived by applying the proportion of O&M costs to total capital in 1968 to the total 1976 capital.

Footnotes

(1) Bramer, H. C., The Economic Aspects of Water Pollution Abatement Program in the Ohio River Valley," Doctoral Dissertation, University of Pittsburgh, 1960.

(2) Environmental Protection Agency, The Economics of Clean Water, 1972.

SECTION V

ESTIMATING WATER QUALITY AS A FUNCTION OF POLLUTION CONTROL

The methodology described herein is for estimating pollution costs as a function of water quality and abatement costs as a function of degree of pollution control. At first glance, this may appear to be a trivial discrepancy in terminology. Unfortunately, that is not the case. If for example, BOD levels in effluent were reduced by 90 percent during the next five years in a given basin, the BOD level of the basin's surface water would probably not be reduced by exactly 90 percent. Water quality must be estimated as a function of pollution control efforts before meaningful cost comparisons can be made.

Traditionally, the quality/control relationship has been implicitly included in the benefit estimates or the cost estimates. An excellent example of such a methodology is provided by Matson and Bennett in their study of the Maumee River Basin where both benefits and costs are estimated as a function of degree of pollution control (1) (see Exhibit V-1). Although such a technique may simplify computational requirements and yield comparable benefit and cost curves, the shortcomings are far more significant. The physical relationships involved in pollution control processes are placed in a passive exogenous setting and benefit estimates become dependent upon the accuracy of quality/control estimates which are hidden from view. Benefit estimates in such cases can, at best, be only as good as the quality/control estimates. Also, this approach requires developing different benefit functions for areas with different quality/control relationships even if the relevant economic characteristics of the areas are identical. In summary, such an approach may be acceptable for specific problem or crisis oriented studies but does not exhibit the flexible characteristics requisite for a national pollution control study.

EPA has recognized the need for relating pollution loads to water quality. For example, in describing the relationship of their classification system for pollution sources and their pollution index system, they state:

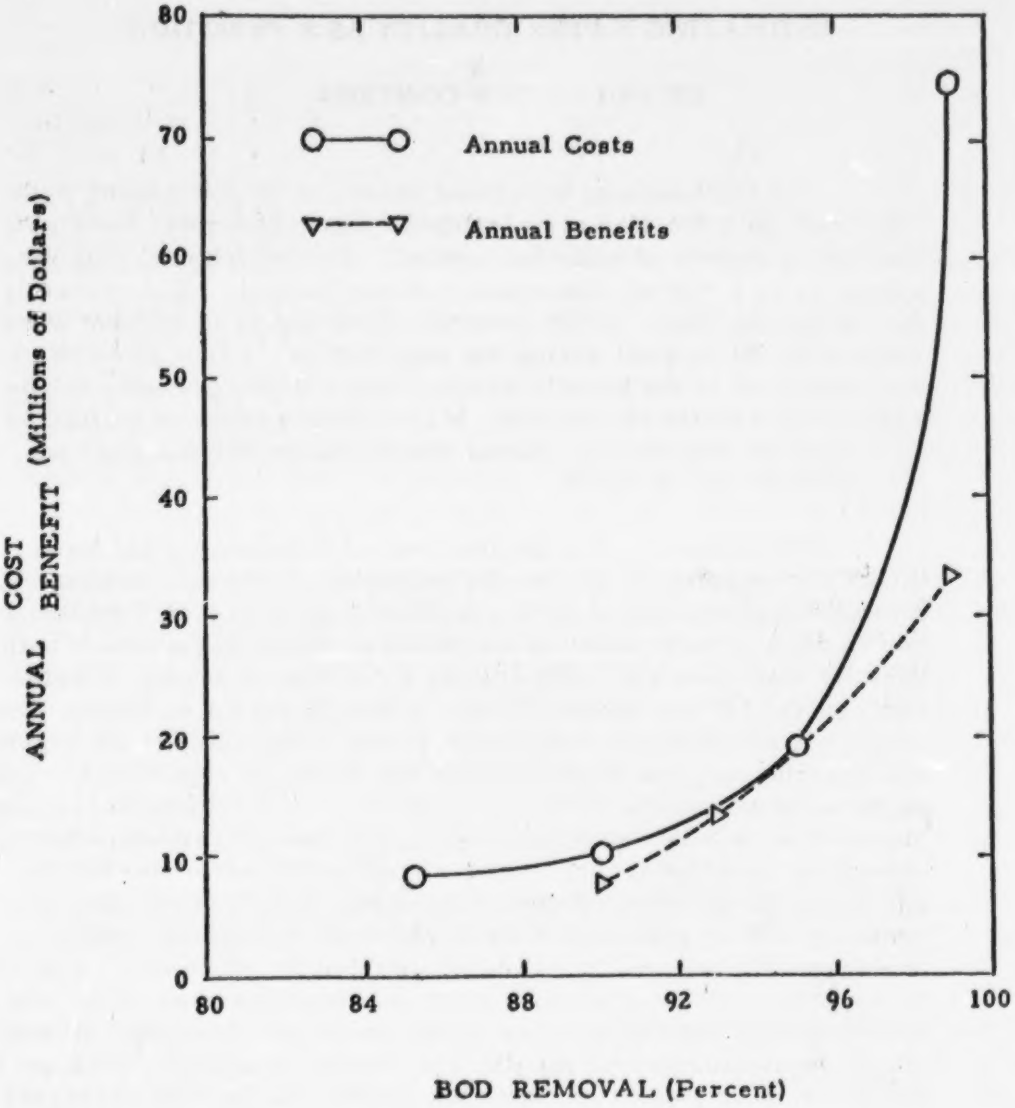


Exhibit V-1. Effect of degree of removal of dissolved organic matter from effluents on annual costs and economic benefits due to pollution abatement in the Maumee River Basin.

Source: Matson, Jack V. and Bennett, Gary F., "Cost of Industrial and Municipal Waste Treatment in the Maumee River Basin," Water-1969, Lawrence K. Cecil (ed.), Chemical Engineering Progress Symposium Series, Vol. 65, No. 97, American Institute of Chemical Engineers, New York, 1969.

> The pollution source allocation is intended to produce a picture of the relative contributions of various activities that are pollution sources (note that not all activities or waste discharges necessarily result in pollution, as defined) to the situation reflected in the index. Precious efforts to establish such a ranking were hindered by a lack of correspondence of source contributions with geographically unique indicators of the resulting stream pollution and its effects. In addition to offering progress to the goal of associating discharges with pollution impacts, the present approach provides a means of unambiguously aggregating measures of source contributions to meet higher level planning information needs. (2)

Recognizing the necessity for relating water quality to pollution control levels on a national basis, the literature was searched for proven methodology. The results of the search pointed out a crying need for further study in this research area since published articles which treated the topic in anything more than casual reference could not be found. If further searches of the literature were undertaken, the prospects of discovering significant references appear dim.

Since quality/control functions are a key determinant in the analysis set forth herein, and in view of the lack of acceptable documented approaches, we have undertaken the development of such a methodology. Our suggested approach is summarized below, prefaced with general discussions on measuring water quality, determinants of water quality and measuring the degree of pollution control.

A. Measuring Water Quality

Water quality is a nebulous term normally used in describing the abundance of pollutants in a sample of water or the suitability of a water source for a given use. The former interpretation implies physical, chemical and biological properties while the latter interpretation includes properties which are more appropriately termed esthetic qualities.

Hence, one can speak of physical water quality, esthetic water quality or composite water quality where both physical and esthetic properties are combined. Some commonly used water quality measurements are listed in Exhibit V-2.

Given a set of water quality measurements, a classification problem exists in ranking the quality of surface waters. One classification system ranks water as either potable (i.e., fit for human consumption) or non-potable. This classification system is based upon a set of physical, chemical, and biological measures as illustrated in Exhibit V-3. Since a large proportion of municipalities in the U.S. pretreat their water supplies and large amounts of water are used for purposes other than human consumption, potability isn't an adequate classification system for this study. Another classification system is used to reflect the degree of hardness while still another is tied to the degree of salinity (Exhibit V-4). Some studies have ranked water quality on the basis of other singular criterions such as dissolved oxygen and biochemical oxygen demand. Although these are of interest they are not adequate for the current study.

In 1968, the National Technical Advisory Committee on Water Quality Criteria set forth water quality recommendations for general use classifications (3). Their recommendations could, in most cases, be interpreted as guidelines for judging water as suitable or not suitable for a given use. In some instances, ranges of acceptable quality measurements were defined. Similar water quality guidelines have been formulated by other agencies with California's efforts probably being the most notable example. (4)

In 1971, Prati, Pavanello and Pesarin presented a method for ranking water quality with an index number ranging from 1 to 8 (5). The criteria they proposed are presented in Exhibit V-5. Unfortunately, their system is based solely upon physical considerations.

In January, 1972 Battelle's Columbus Laboratories reported the development of an environmental evaluation system for water resource planning (6). Developed for the U.S. Bureau of Reclamation, the system ranks composite environmental quality on a scale of 0 to 1000. Components and associated weights for their system are presented in Exhibit V-6. The system seems to be the most comprehensive environmental quality ranking scheme developed to date and is currently being further refined in a contract with the Arizona Department of Economic Planning and Development (7).

Exhibit V-2. Selected water quality characteristics

Physical Characteristics	Esthetic Characteristics
Biochemical oxygen demand (BOD)	Taste
Dissolved oxygen (DO)	Appearance
Chemical oxygen demand (COD)	Odor
Fecal Coliform bacteria	Floating materials
Total dissolved solids (TDS)	Shoreline appearance
Total suspended solids (TSS)	Biota
Hydrogen-ion concentration (pH)	Man-made objects
Inorganic phosphate	Human interest
Inorganic nitrogen	
Inorganic carbon	
Temperature	
Hardness (as $CaCO_3$)	
Specific electric conductance	
Radioactivity	
Toxic substances (including pesticides)	
Turbidity	
Color	
Oil	

Source: Dee, Norbert, et al., Environmental Evaluation System for Water Resource Planning, Battelle Columbus Laboratories for Bureau of Reclamation, U. S. Department of the Interior, Washington, 1972.

Chow, Ven Te (ed.), Handbook of Applied Hydrology, McGraw-Hill, New York, 1964.

Todd, David Keith (ed.), The Water Encyclopedia, Water Information Center, Port Washington, N. Y.

Exhibit V-3. Drinking water standards of the U.S. Public Health Service, 1962.

A. General Constituents

Substance	Recommended limits of concentrations, in mg/l	Mandatory limits of concentrations, in mg/l
Alkyl benzene sulfonate (ABS)	0.5	--
Arsenic (As)	0.01	0.05
Barium (Ba)	--	1.0
Cadmium (Cd)	--	0.01
Carbon chloroform extract (CCE)	0.2	--
Chloride (Cl)	250	--
Chromium (hexavalent) (Cr^{+6})	--	0.05
Copper (Cu)	1.0	--
Cyanide (CN)	0.01	0.2
Fluoride (F)	*	*
Iron (Fe)	0.3	--
Lead (Pb)	--	0.05
Manganese (Mn)	0.05	--
Nitrate (NO_3)**	45	--
Phenols	0.001	--
Selenium (Se)	--	0.01
Silver (Ag)	--	0.05
Sulfate (SO_4)	250	--
Total dissolved solids (TDS)	500	--
Zinc (Zn)	5	--

*See below

**In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

B. Fluoride

Annual average of maximum daily air temperatures, in degrees Fahrenheit	Recommended control limits - fluoride concentrations, in mg/l		
	Lower	Optimum	Upper
50.0 - 53.7	0.9	1.2	1.7
53.8 - 58.3	0.8	1.1	1.5
58.4 - 63.8	0.8	1.0	1.3
63.9 - 70.6	0.7	0.9	1.2
70.7 - 79.2	0.7	0.8	1.0
79.3 - 90.5	0.6	0.7	0.8

Exhibit V-3 (continued)

C. Radioactivity

Source	Recommended limits, micromicrocuries per liter
Radium - 226	3
Strontium - 90	10
Gross beta activity	1,000

Source: Todd, David Keith (ed.), The Water Encyclopedia, Water Information Center, Port Washington, N. Y.

Exhibit V-4. Classification of water quality according to hardness and salinity properties.

A. Based on Concentration of Total Dissolved Solids

Name	Concentration of Total Dissolved Solids, parts per million
Fresh	0-1,000
Brackish	1,000-10,000
Salty	10,000-100,000
Brine	More than-100,000

B. Based on Hardness

Name	Hardness as $CaCO_3$, Parts per million
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	More than 180

Source: Todd, David Keith (ed.), The Water Encyclopedia, Water Information Center, Port Washington, N.Y.

Davis and DeWiert, Hydrogeology, John Wiley and Sons, 1966.

Anonymous, various publications of the U. S. Geological Survey, Washington.

Exhibit V-5. Assessment of surface water quality by a single index of pollution

	Classification of Surface Water Quality				
Condition:	Excellent	Acceptable	Slightly Polluted	Polluted	Heavily Polluted
Index of quality:	1	2	4	8	≥ 8
Quality Characteristic					
pH	6.5-8.0	6.0-8.4	5.0-9.0	3.9-10.1	≤3.9-≥10.1
Dissolved oxygen	88-112	75-125	50-150	20-200	≤20-≥200
BOD (ppm)	1.5	3.0	6.0	12.0	≥12.0
COD (ppm)	10	20	40	80	≥80
Permanganate(mgl-0) (Kubel test)	2.5	5.0	10.0	20.0	≥20.0
Suspended solids (ppm)	20	40	100	278	≥278
NH_3 (ppm)	0.1	0.3	0.9	2.7	≥ 2.7
NO_3 (ppm)	4	12	36	108	≥108
Cl (ppm)	50	150	300	620	≥620
Iron (ppm)	0.1	0.3	0.9	2.7	≥ 2.7
Manganese (ppm)	0.05	0.17	0.5	1.0	≥ 1.0
ABS (ppm)	0.09	1.0	3.5	8.5	≥ 8.5
CCE (ppm)	1.0	2.0	4.0	8.0	≥ 8.0

Source: **Prati, L., Pavanello, R. and Pesarin, F., "Assessment of Surface Water Quality by a Single Index of Pollution," Water Resources Research (GB), No. 5, pp. 741-51, 1971.**

Exhibit V-6. Battelle's Environmental Evaluation System

Components	Parameter Importance Units *1
Ecology	240
Species and Population	140
Terrestrial	
Browsers and grazers	14
Crops	14
Natural Vegetation	14
Pest species	14
Upland game bird	14
Aquatic	
Commercial fisheries	14
Natural Vegetation	14
Pest species	14
Sport fish	14
Waterfowl	14
Habitats and Communities	100
Terrestrial	
Food web index	12
Land use	12
Rare and endangered species	12
Species diversity	14
Aquatic	
Food web index	12
Rare and endangered species	12
River characteristics	12
Species diversity	14
Ecosystems	
Descriptive only	

Exhibit V-6 (continued)

Components	Parameter Importance Units *1
Environmental Pollution	402
Water Pollution	318
Basic hydrolic loss	20
BOD	25
Dissolved Oxygen	31
Fecal coliforms	18
Inorganic carbon	22
Inorganic nigrogen	25
Inorganic phosphates	28
Pesticides	16
pH	18
Stream flow variation	28
Temperatures	28
Total dissolved solids	25
Toxic substances	14
Turbidity	20
Air Pollution	52
Carbon monoxide	5
Hydrocarbons	5
Nitrogen Oxides	10
Particulate matter	12
Photochemical oxidants	5
Sulfur oxides	10
Other	5
Land Pollution	28
Land use	14
Soil erosion	14
Noise Pollution	4
Noise	4

Exhibit V-6 (continued)

Components	Parameter *1 Importance Units
Esthetics	153
Land	32
Geologic surface material	6
Relief and topographic character	16
Width and alignment	10
Air	5
Odor and visual	2
Sounds	2
Water	52
Appearance of water	10
Land and water interface	16
Odors and floating material	6
Water surface area	10
Wooded and geologic shoreline	10
Biota	24
Animals - domestic	5
Animals - wild	5
Diversity of vegetation types	9
Variety within vegetation types	5
Man-made objects	10
Man-made objects	10
Composition	30
Composite effect	15
Unique composition	15

Exhibit V-6 (continued)

Components	Parameter *1 Importance Units
Human Interests	205
Educational/Scientific Packages	48
Archeological	13
Ecological	13
Geological	11
Hydrological	11
Historical Packages	55
Architecture and Styles	11
Events	11
Persons	11
Religious and Cultures	11
"Western Frontier"	11
Cultures	28
Indians	14
Other ethnic groups	7
Religious groups	7
Mood/Atmosphere	37
Awe-inspiration	11
Isolation/solitude	11
Mystery	4
"Oneness" with nature	11
Life Patterns	37
Employment Opportunities	13
Housing	13
Social Interaction	11

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*1 Total parameter importance units equals 1000.

Source: Dee, Norbert, et al., Environmental Evaluation System for Water Resource Planning, Battelle Columbus Laboratories for Bureau of Reclamation, U. S. Department of the Interior, Washington, 1972.

Another significant water quality classification methodology is the PDI (pollution prevalence, duration, intensity) system being utilized by the Environmental Protection Agency (2). The PDI has the distinct disadvantage of being tied to legal criteria. If quality is such that damages are occurring to some beneficial uses but legal criteria are being met, the water apparently is still rated as high quality. Furthermore, the measurements upon which the PDI are dependent (Exhibit V-7) are rather arbitrary and may prove difficult to apply consistently. The relative weights given to ecological, utilitarian and esthetic aspects of pollution could be questioned. Even though the PDI has several undesirable attributes, it is, perhaps, the most widely applied composite water quality classification system.

Currently, Federal, state and local agencies are operating thousands of water quality monitoring stations. Results from many of these stations are recorded in the STORET data retrival system maintained by the Environmental Protection Agency. It is also reported that the U.S. Geological Survey maintains a large file of water quality data. An abundance of water quality data appears to be available. These data should be sufficient to meet the needs of physical quality classification systems such as the 8 point system proposed by Prati, Pavanello and Pesarin but generally fall short of providing the requisite esthetic data for a system such as the one developed by Battelle. EPA's PDI system is being applied on a nation-wide basis and the results are available.

B. Determinants of Water Quality

In examining the relationship between water quality and pollution control levels, it is necessary to consider the physical processes which determine quality of surface waters. Of course, one of the primary determinants of quality is the quantity and type of pollutants entering the body of water. However, of equal importance is the inherent ability of surface waters to naturally purify themselves through their capacity to assimilate wastes.

Exhibit V-7. Components of the PDI water quality measurement system[a]

Component	Possible values
Prevalence of pollution[b]	[c]
Duration of pollution	0-1.0
Consecutive days ≤ 91	0.4
92 ≤ consecutive days ≤ 183	0.6
184 ≤ consecutive days ≤ 274	0.8
Consecutive days ≥ 275	1.0
Intensity of pollution	0-1.0
Ecological	0-0.5
Utilitarian	0-0.3
Esthetic	0-0.2

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[a] PDI = (prevalence) (duration) (intensity)

$$\text{pollution index} = \frac{\text{PDI}}{\text{total stream miles}}$$

[b] A pollution zone is defined as a surface water area not consistently in compliance with legal criteria for water quality.

[c] Prevalence = length of pollution zone in miles.

Source: Anonymous, The Economics of Clean Water, Vols. I and II, U. S. Environmental Protection Agency, Washington, 1972.

The following discussion by Sheppard T. Powell is quoted from Chow's hydrology handbook:

> The waste-assimilative capacity of surface waters is generally considered to be the amount of waste which will not cause water-quality deterioration beyond the limits required for other beneficial uses of the supply. Because oxygen-demanding wastes are most frequently encountered, this capacity is commonly given in terms of the bio-chemical oxygen demand (BOD) of the waste. Other wastes are very important in determining the assimilative capacity, however, and BOD should not be assumed the only criterion.
>
> The greatest single factor controlling the overall waste-assimilative capacity of surface waters is the amount of dilution that is provided. ...
>
> The primary factors controlling the BOD assimilative capacity are dilution, temperature, and the relative rates of biochemical deoxygenation and atmospheric reoxygenation. (8)

Typical assimilative capacities for various types of streams are shown in Exhibit V.-8.

Powell further notes that different kinds of surface water bodies typically have different levels of assimilative capacity. Usually, water quality in an impoundment will be better than the average quality of the influent stream. The mixing of fresh water and sea water in estuaries present a large array of unique quality considerations. (8)

Sources of surface water pollutants may be classified as meterologic, domestic, industrial, and agricultural (9). In addition, consumptive use increases the concentration of suspended and dissolved solids. The primary components in each of these classifications are listed in Exhibit V-9.

Exhibit V-8. Total assimilative capacity of streams of different orders.

Stream order	Average discharge (cfs)	Average depth (ft)	Average velocity (ft per sec)	Coefficient of reaeration (day^{-1})	Total length of streams (miles)	Total assimilative capacity (Tons per day per unit deficiency in dissolved oxygen)	U.S. rivers representative of each order
1	0.6	....	....	....	1,570,000	....	....
2	2.8	....	....	....	810,000	....	....
3	14	0.55	1.2	9.3	420,000	16,300	....
4	65	.95	1.6	5.5	220,000	19,000	....
5	310	1.8	1.8	2.6	116,000	20,000	Pecos
6	1,500	2.7	2.0	1.8	61,000	30,000	Shenandoah, Raritan.
7	7,000	5	2.5	1.0	30,000	31,000	Allegheny, Kansas, Rio Grande.
8	33,000	12	3.0	.37	14,000	21,000	Tennessee, Wabash.
9	160,000	25	4.0	.19	6,200	18,000	Columbia, Ohio
10	700,000	45	5.0	.10	1,800	9,400	Mississippi

Source: Todd, David Keith (ed.), The Water Encyclopedia, Water Information Center, Port Washington, N. Y.

Anonymous, various publications of the U. S. Geological Survey, Washington.

Exhibit V-9. Sources of surface water pollutants

Contributing factor	Principal quality input to surface waters
Meteorologic	Dissolved gases native to atmosphere
	Soluble gases from man's industrial activities
	Particulate matter from industrial stacks, dust, and radioactive particles
	Material washed from surface of earth, e.g.:
	Organic matter such as leaves, grass, and other vegetation in all stages of biodegradation
	Bacteria associated with surface debris (including intestinal organisms)
	Clay, silt, and other mineral particles
	Organic extractives from decaying vegetation
	Insecticide and herbicide residues
Domestic use	Undecomposed organic matter, such as garbage ground to sewer, grease, etc.
	Partially degraded organic matter such as raw wastes from human bodies
	Combination of above two after biodegradation to various degrees of sewage treatment
	Bacteria (including pathogens) viruses, worm eggs
	Grit from soil washings, eggshells, ground bone, etc.
	Miscellaneous organic solids, e.g., paper, rags, plastics, and synthetic materials
	Detergents
Industrial use	Biodegradable organic matter having a wide range of oxygen demand
	Inorganic solids, mineral residues
	Chemical residues ranging from simple acids and alkalies to those of highly complex molecular structure
	Metal ions
Agricultural use	Increased concentration of salts and ions
	Fertilizer residues
	Insecticide and herbicide residues
	Silt and soil particles
	Organic debris, e.g., crop residues

Source: Todd, David Keith (ed.), The Water Encyclopedia, Water Information Center, Port Washington, N.Y.

McGauhey, Engineering Management of Water Quality, McGraw-Hill, New York, 1968.

Another method of classifying pollutant sources divides sources into natural and man-made. Each of these can be further divided into point and non-point sources in reference to concentrated effluents like municipal sewage (point) as opposed to dispersed effluents such as runoff from agricultural lands (non-point). Since the relationship of such a classification system to the one presented in Exhibit V-9 is obvious, a detailed enumeration of the natural versus man-made system is omitted for brevity.

C. Measuring Water Pollution Control Levels

As with water quality, various methods are utilized to describe degrees of pollution control. One commonly used method is that of describing the general control technique being used. Some agencies, such as the U.S. Census Bureau (10) typically report water pollution control as none, primary, secondary or tertiary. Others are more specific and describe the actual physical configurations of the treatment systems being utilized. Such a measuring system has the shortcomings of not accounting for pretreatment of industrial wastes which are later treated in municipal sewage plants, not specifically stating the quality of the effluent and not reflecting the magnitude of effluent flows.

A slightly better approach consists of specifying the proportion of specific pollutants (e.g., organics measured as BOD) which are removed from the effluent on a source by source basis. However, such methodology yields substantial aggregation problems due to differential effluent loads by source.

If one wishes to define degree of control as a percentage or proportion, the most tractable approach consists of stating the proportion of each specific pollutant removed throughout the region being studied. Even this approach has its problems since pollution control technology, industrial activity, etc. may vary substantially within the study area. Also, total pollutant inflow into surface waters can not be specified unless both raw effluent flows and concentrations are known.

Unfortunately, even specification of total quantity of pollutants contained in the treated effluent does not solve all the problems. Distribution of the effluent is important in how it affects water quality and some effluents may never reach surface waters. Also, relating water quality to each kind of pollutant could generate massive computational requirements while a common denominator for combining dissimilar pollutants into one aggregate measure is not readily at hand.

In summary, it seems any conventional means of measuring or classifying the degree of pollution control creates some methodological problems.

D. Aggregation

Measuring water quality or pollution control effectiveness at a given geographic point at a given point in time is much simpler than relating the level of pollution control to water quality on a national or even a regional basis. Neither surface water quality nor effluent quality is consistent over time. Water quality varies with a host of influencing factors including flow, temperature and differential effluent loads due to seasonal variations in economic activity. Likewise, effluent quality from a given treatment plant may vary with throughput and a variety of operating conditions. To illustrate the variability in surface water quality, the reader is referred to Exhibit V-10 which states variations in dissolved solids and sediment concentrations of major basins in the arid and semi-arid portions of the United States. It is also noted that the effectiveness of most treatment systems is described in terms of probabilities. For example, a system might remove 90 percent of the BOD load 90 percent of the time.

Hence, when one speaks of relating benefits to water quality it is implicitly assumed that water quality is being reflected as an average measure. The same is true for relating costs to degree of control. Recognizing that surface water and effluent quality data are often available on a temporal sampling basis as opposed to a continuous monitoring basis, such samples must be aggregated to yield a composite average annual quality measure. The simplest method of aggregating such data over time is to compute the simple average of the sample values. If the samples are not uniformily distributed through time, the samples may first be adjusted to reflect relative time weights. Alternatively, samples may be weighted by rate of flow to more accurately reflect total volume of pollutant loads.

Exhibit V-10. **Variations in Dissolved Solids and Sediment Concentrations in Major River Basins in Arid and Semiarid United States**

Region	Dissolved solids concentrations, mg/l From	Dissolved solids concentrations, mg/l To	Sediment concentrations, mg/l [1/] From	Sediment concentrations, mg/l [1/] To
Columbia River Basin	<100	300	<200	300
Northern California	<100	700	<200	+500
Southern California	<100	+2,000	<200	+15,000
Colorado River Basin	<100	+2,500	<200	+15,000
Rio Grande Basin	<100	+2,000	+300	+50,000
Pecos River Basin	100	+3,000	+300	+7,000
Western Gulf of Mexico Basins	100	+3,000	<200	+30,000
Red River Basin	<100	+2,500	+300	+25,000
Arkansas River Basin	100	+2,000	+300	+30,000
Platte River	100	+1,500	+300	+7,000
Upper Missouri River Basin	100	+2,000	<200	+15,000

[1/] Sediment concentration = $\frac{\text{Annual Load}}{\text{Annual Streamflow}}$

Source: Anonymous, Water Quality Criteria, National Technical Advisory Committee on Water Quality Criteria, Federal Water Pollution Control Administration, U. S. Department of the Interior, Washington, 1968.

EPA's PDI system utilizes still another approach for assessing surface water quality with emphasis placed upon number of consecutive days that the water quality doesn't meet legal quality criteria (see Exhibit V-7). A final approach might be to weight the surface water quality samples by rate of surface water utilization for beneficial uses. Procedures utilized in published sources varies with no universally accepted technique apparent. It is suggested that the technique which is most appropriate depends upon the end use of the data and the overall methodology employed in the study. Recommendations for temporal quality aggregations in reference to national analysis of pollution control efforts are presented in the final section of this chapter.

The geographic dispersion of water quality sampling stations presents similar problems. Water quality often varies substantially along a given stream. Typically, quality of a stream tends to increase as one moves from the mouth toward the source. Although some researchers indicate a need for one aggregate national water quality number, we feel such a measurement would not be meaningful in terms of a comparison of national pollution costs and control costs. Furthermore, such measurements for major basins seem undesirable. For example, the Missouri River is of very low quality downstream of Omaha. However, some of the upper reaches of the Missouri are of much higher quality. To average the quality for the entire Missouri River Basin would seem to be an extreme sacrifice of accuracy for computational expediency unless an elaborate aggregation methodology was employed. It seems more reasonable to look at sub-basins or even zones within sub-basins such that the geographic study area exhibits a fairly constant level of water quality. Aggregation of water quality over sub-basins or zones even poses methodology problems.

As with time considerations surface water quality data may be geographically aggregated by taking the simple geographic average of average annual quality for the sampling stations. However, such a simplistic approach ignores the distribution of beneficial uses and sampling stations. An approach like that utilized in the PDI system resolves the latter problem but doesn't adequately account for the distribution of beneficial uses. We feel the best approach would be to assign a population base to each sampling station and then weightthe samples on the basis of population. However, we have not been able to isolate studies utilizing this latter approach. Even the population weighting scheme has the disadvantage of not correctly weighting water quality in low population areas with high recreational or ecological value. To reflect non-population associated benefits, one could add a consideration for geographic area represented into the weighting methodology. Several other variations could also be proposed but, need not be elaborated at this point.

Degree of control adds yet another dimension to the aggregation problem. Effluent discharges are not evenly distributed throughout a given study area and the effluent load generated within an area has an impact upon the quality of surface waters in downstream areas. It must also be recognized that the type of treatment and operational effectiveness of treatment processes will vary by effluent source. Data on effluent quality is not as readily available as surface water quality data but, similar aggregation techniques are applicable where data are available.

E. Recommended Approach

The purpose of this section is to recommend an approach for relating degree of control to surface water quality within a national water pollution control assessment framework. The suggested approach is in keeping with the short run, partial equilibrium methodology outlined in Chapter II. It is felt that data required for the recommended approach is consistent with long term planning requirements. However, it must be stressed that this approach has been developed for short term planning purposes only and is not an adequate methodology when viewed in terms of general equilibrium analysis which should be preferred in the longer run. Furthermore, the reflection of physical relationships is cast in a rather subjective setting since no rigorous approach is currently available which could be applied on a national basis given reasonable time and budget constraints.

Specific Measurements

For the purposes of this study the water quality characteristics displayed in Exhibit V-11 have been adopted as measurements of water quality. For current purposes, we do not foresee a need nor the utility to aggregate all characteristics into a composite index. This does not, however, mean that we suggest further work with composite indices should be abondoned. Indices such as the PDI can play a very important role in water quality monitoring and other research areas and should be further pursued. Even though some esthetic measures are included in the list, it is recognized that in many cases such data are not readily available. For a further discussion of specific measurements, the reader is referred to Appendix A of this report.

Water Quality Assumptions

If the analytical procedures adopted for assessing national pollution control efforts are to be tractable, a number of water quality assjmptions are necessary. For brevity, the assumptions adopted herein are listed below in list form.

1. Average levels of water quality within a geographic area are adequate for current purposes--i.e., daily quality variations will be ignored.

2. The quality for any given surface water body at 100 percent point pollution control can be estimated.

3. The quality for any given surface water body at 100 percent control of all man-made pollutants (i.e., point and non-point) can be estimated.

4. The quality impacts of natural pollution will be taken as an exogenous factor.

5. The cyclic impact of water pollution control upon air quality which, in turn, affects the quality of meterologic water and then surface waters will be ignored.

6. Current water quality and water quality at 100 percent point and point plus non-point pollution control can be taken as three points on the same curve and the shape of that curve can be subjectively derived for any given surface water body.

Exhibit V-11. Water quality characteristics adopted for this study

Physical Characteristics

- Biochemical oxygen demand
- Chemical oxygen demand
- Fecal coliform bacteria
- Total dissolved solids
- Total suspended solids
- Hydrogen-ion concentration (pH)
- Inorganic phosphate
- Inorganic nitrogen
- Toxic substances and trace elements **/
- Hardness (as $CaCO_3$)
- Temperature
- Radioactivity
- Color
- Turbidity
- Oil

Esthetic Characteristics

- Floating solids
- Taste
- Odor
- Biota
- Appearance */

---

*/ As used here, appearance is a composite measure including color, turbidity, rate of flow, shoreline appearance, etc.

**/ Includes heavy metals

Water Pollution Control Assumptions

As with water quality, assumptions concerning water pollution control levels are also necessary. They are as follows:

1. Current levels of pollution control in any given area can be generalized to a specific strategy.

2. Both non-point and point pollution are critical but comprehensive data for the former will limit its analysis.

3. Seasonal variations in effluent flow and quality will be included to the extent available but it is anticipated that annual averages will be used in most cases due to data limitations.

Relating Quality to Abatement

The general form of the surface water quality level of abatement relationship is as depicted in Exhibit V-12. One such relationship is required for each pollutant or water quality measurement in each sub-basin or pollution zone. It is noted that the relationships for one specific water quality characteristic is not necessarily independent of other water quality characteristics. Care must be taken to adequately reflect these synergistic relationships even if it requires a separate set of quality abatement curves for each abatement strategy to be considered. To the furtherest extent possible, such curves should also be developed for seasons of the year.

Recognizing that surface water quality within a geographic study area may not be uniform, the problem of weighting samples from monitoring stations must be considered. Furthermore, it must be noted that economic activity, biota, senic attractions, etc. are not apt to be uniformily distributed. Hence, an average water quality number designed to most accurately reflect quality for one beneficial use may not be the most appropriate for another beneficial use.

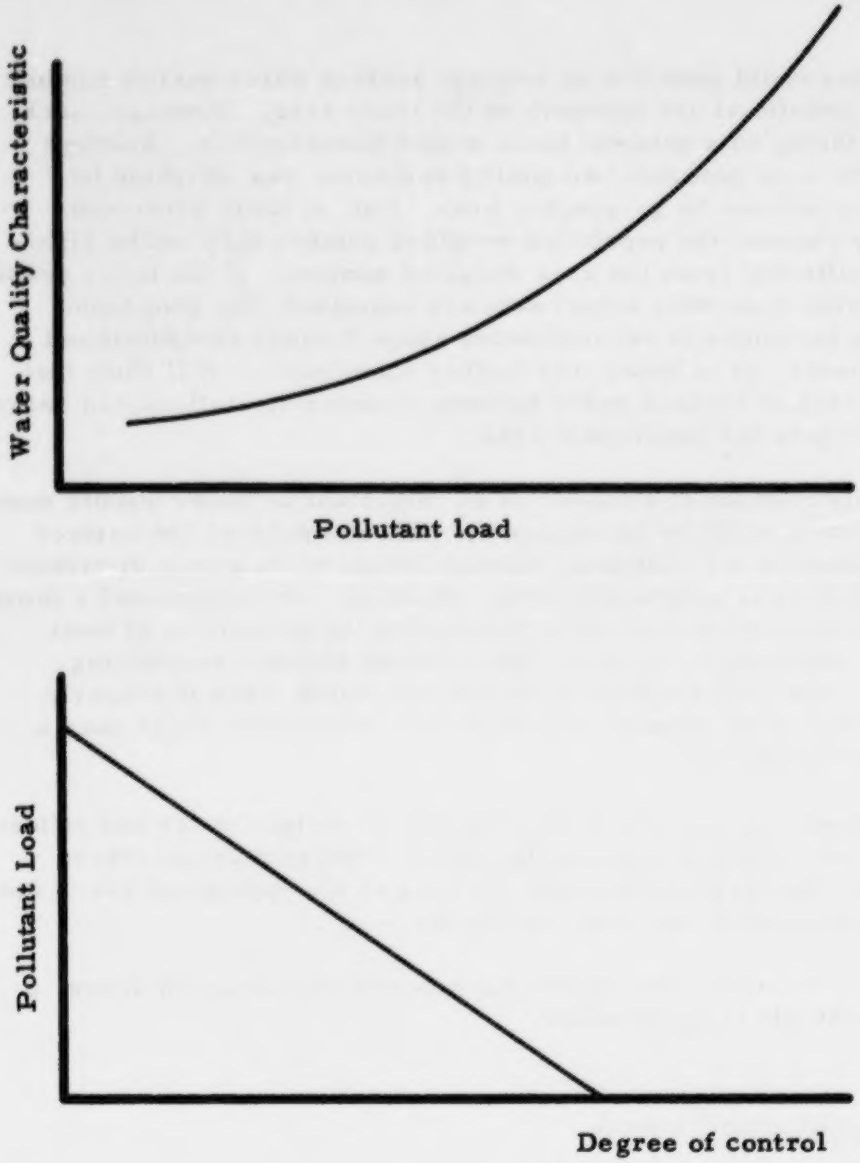

Exhibit V-12. General form of surface water quality - degree of control curves.

One could generate an average surface water quality number for each beneficial use category in the study area. However, such an undertaking on a national basis seems unreasonable. Another possibility is to generate two quality numbers: one weighted by population and one by geographic area. But, if study areas are carefully chosen, the population weighted number may not be significantly different from the area weighted number. If the latter possibility proves true when actual data are examined, the geographic weighting technique is recommended since it eases computational requirements. It is hoped that further examinations will show that average area of surface water between monitoring stations can serve as a surrogate for geographic area.

Distribution of effluents is as important as water quality samples. One approach would be to assume all effluents entered the surface water system at its centroid. Another would be to evenly distribute it with respect to geographic area. However, we recommend a more difficult approach which entails estimating the proportion of total effluents entering the surface water system between monitoring stations. The latter approach seems warranted since it properly accounts for large effluent concentrations which may occur near a study area boundary.

Given appropriate measurements of surface water and effluent quality, the impact of a given abatement strategy must be traced throughout the length of a basin, starting at the uppermost reach and progressing toward the lower end of the basin.

To illustrate and clarify the procedures discussed above, a simple **example** is given below.

F. An Illustrated Example

When describing a methodology, it is sometimes beneficial to illustate its application. Such an approach is taken in this final section describing the relationship of degree of pollution control and water quality. Even though an hypothetical example would have sufficed, it was felt a real world example would be more meaningful. In the following example, we have combined some hypothetical and subjective elements with, hopefully, enough actual data to yield a meaningful illustration.

Municipal and industrial effluent data representative of the Maumee Sub-basin of the Lake Erie Basin were adapted from Matson (11). Water quality data for one year at the mouth of the same sub-basin were adapted from the U.S. Public Health Service (12). The data was subjectively modified to adjust for what seemed to be unusual circumstances. In an actual study, examination of more than one year's water quality data would be required but, such an undertaking would have further delayed preparation of this report and, hence, seemed unwarranted for the current illustrative example. The same argument is true for a subjective modification required to place effluent flows and water quality data in the same time frame. Hence, the data should be viewed as hypothetical rather than being truly reflective of the Maumee Sub-basin.

The illustrative sub-basin displays average monthly temperatures ranging from the 20's in January to the 70's in July. Annual precipitation varies from 28 to 40 inches with the average being about 35 inches. The surface waters have high levels of dissolved phosphate and hardness. Plankton flora are abundant and diverse. The sub-basin is roughly circular with a fifty-mile radius encompassing roughly 6,500 square miles. Total stream miles are about 2,800 which includes nearly 300 streams. Land in the sub-basin is very flat with natural conditions without drainage, being predominately heavily wooded marshlands. The soils are fine textured, poorly drained and relatively impermeable. The 1968 population of 1.2 million was centered around Toledo, Lima and Fort Wayne. Industrial activity includes primary and fabricated metals, oil refining, glass, chemicals, machinery, meat packing, brewing and other food processing. Agricultural activity is highly developed with predominant enterprises including vineyards and orchards. The sub-basin includes a number of recreational developments (11, 12).

Raw and treated effluent flows for the illustrative case appear in Exhibit V-13. Nonpoint effluents after treatment were assumed to equal 25 percent of total treated effluents. Both point and nonpoint flows were assumed to be equally distributed throughout the year. Only the BOD load is presented with the implication that other effluent and water quality factors would be handled in the same manner.

Exhibit V-13. Raw and treated effluent flows, illustrative case

Pollutant source	BOD in 1000 lbs/day raw [*]	 after treatment
Point sources		
Municipalities	201	36
Industrial	266	31
Total	467	67
Nonpoint sources	N.A.	22
Total	N.A.	89

[*] N.A. denotes not available

Source: Point flows adapted from Matson, Jack V., Cost of Industrial and Municipal Water Pollution Abatement in the Maumee River Basin, unpublished Master's Thesis, University of Toledo, 1968.

Nonpoint flows are hypothetical estimates.

Water quality at the mouth of the basin varies substantially during the year. BOD levels vary from less than 0.5 to nearly 18 milligrams per liter. Weighting BOD levels in each sample by the period of time between samples yields average levels in milligrams per liter as follows: January-March 8.6, April-June 4.8, July-September 3.5, October-December 7.7. Again, note that these data include subjective adjustments as described above.

By examining conditions of the sub-basin, conditions and water quality data in other areas in the basin and surrounding areas and applying general water quality principals, two more sets of water quality points were estimated: one for 100 percent reduction of point pollution and one for 100 percent reduction of point pollution plus elimination of all non-point man-made pollution. The latter point corresponds to what water quality in the basin would be under natural conditions given current vegetative patterns. These points are presented in Exhibit V-14.

Given the water quality for 1968 conditions, 100 percent point control and 100 percent point and nonpoint control and given effluents for each level of quality, the relationship of pollution level to water quality can be graphed as shown in Exhibit V-14. The curves for the second and fourth quarters of the year do not correspond to what one would anticipate. It is suggested that this is a result of the assumption that nonpoint pollution is evenly distributed throughout the year. Even this simple case points out the inseparability of point and nonpoint pollution in terms of quality impacts. If one were to assume nonpoint pollution was more heavily concentrated in spring and early summer and less heavily concentrated in the remainder of the year, all four curves would display the same basic shape.

Two significant conclusions can be drawn from the relationships depicted in Exhibit V-14. First, water quality varies over time and hence the impact of a pollution abatement strategy will vary over time. Therefore, the benefits accruing from a given strategy will vary over time and the total benefit calculated on an average annual basis may not be the same total benefits calculated on an average quarterly basis (note: benefits are not normally a linear function of quality). Second, the level of nonpoint pollution will partially determine both the magnitude and slope of the quality/pollution curve. Hence, one cannot estimate benefits from a given strategy unless something is known or at least assumed about the level and temporal distribution of non-point pollution. Acceptance of this latter conclusion places almost all previously published benefit studies in a questionable light.

One further step is required to allow comparisons of benefits and costs: relating degree of pollution control to total effluent load. That relationship is depicted in Exhibit V-15. The vertical intercept is the total raw wasteload from point sources. The dashed line corresponds to an 85 percent reduction in effluent BOD--i.e., an after treatment load of 67,000 pounds per day as shown in Exhibit V-13. Note that degree of control is stated in terms of point pollution only. This approach is taken to provide consistency with data generally found in the literature. However, if so desired, one could easily relate total effluent load to average degree of treatment for all pollution sources including both point and non-point.

Now given Exhibits V-14 and V-15, benefits and costs could be meaningfully compared as described in the preceding chapters of this report.

Before concluding this chapter, one further comment seems pertinent: the relationships depicted in Exhibit V-14 tend to be dynamic while those depicted in Exhibit V-15 are static. With increasing levels of population and economic activity, the vertical intercepts of the latter functions become higher and higher. In other words, it requires a higher degree of treatment to maintain the same level of water quality. Alternatively, gaines in treatment efficiency may be equally offset by increases in the total raw wastewater flow. Hence one can correctly conclude that if water quality remains constant over time and economic activity increases,, total benefits will increase and cost of control per capita will increase. If per capita pollution costs remain constant while per capita costs of control increase, this conclusion is highly significant since the economic justification for truly high quality water would diminish over time. We feel, however, that technological advances in the waste treatment industry may well offset this effect, at least in the short run. Also, when so called benefits from pollution control are viewed in the more appropriate framework of costs of pollution, it may be possible to demonstrate that per capita costs of pollution increases as the economy and populus expands.

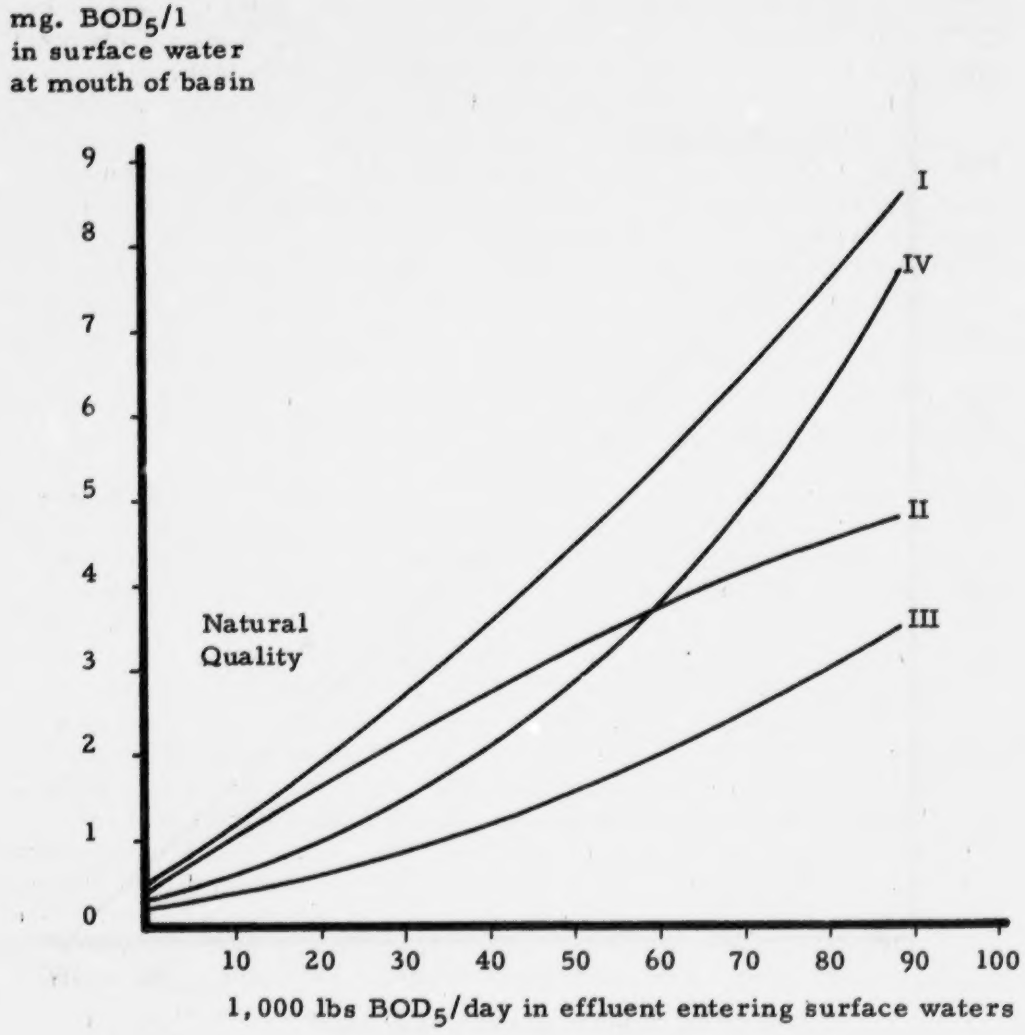

Exhibit V-14. Surface water quality as a function of effluent load, BOD by quarter of year, illustrative example.

I = January - March
II = April - June
III = July - September
IV = October - December

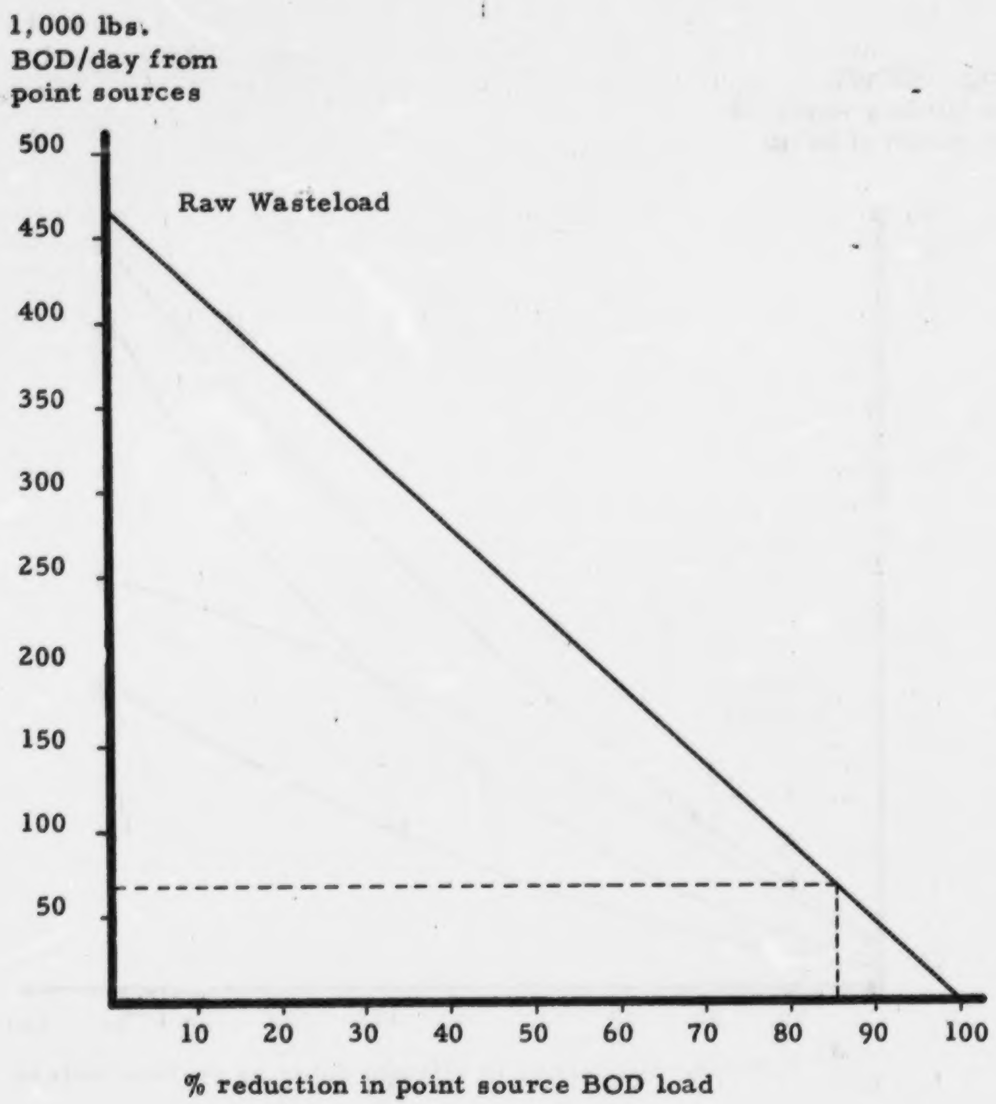

Exhibit V-15. BOD content of treated effluent as a function of degree of treatment, illustrative case.

Footnotes

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SECTION VI

CONCLUSIONS AND DIRECTION OF FUTURE WORK

The preceding chapters have gone considerably beyond a simple enumeration of research needs and priorities. This was not a calculated extension but rather was the inevitable byproduct of preliminary attempts to establish research needs and priorities in an area of endeavor that is relatively unexplored and besieged with controversy. Many have studied the water quality problem but very few have had the courage or found it necessary to venture out of the protective shelter provided by the convenient simplifying assumptions amenable to and associated with estimating isolated water quality impacts or even comprehensive impacts for a small geographical area. By changing the scope of the problem from selected water quality impacts to comprehensive national impacts the problem is transformed into a very circuitous task that seems to collapse at every point and thereby becomes almost totally defiant of solution. In this regard economics as a profession has not assisted the policy-maker in his need for acquiring immediate answers so as to successfully allocate limited time, effort and resources to these areas representing the greatest current need. It is felt that the expanded scope of this part of the project has been a valuable expenditure of time in that many firm conclusions have been reached. These include hypothesized results that might be expected from extending previously conducted studies to derive national benefit cost estimates, subjective judgments of areas of emphasis and research needs, and possible results of further research. It is therefore fitting that as a concluding note some of the salient points are briefly summarized. These items are briefly enumerated and discussed under several categories: methodological conclusions, benefit cost estimation and state-of-the-arts. It further behooves us to present these conclusions in the most summarized and straightforward manner possible.

A. Methodological Conclusions

It is indeed unfortunate that many of the methodological limitations have not been satisfied prior to this point in time. In general, the conclusions in reference to methodology are as follows:

1. General equilibrium models, preferred on a theoretical basis, are not currently implementable. Sizeable data problems, and lack of sufficient sensitivity to natural, physical and socioeconomic considerations prevent the

general equilibrium approaches from being utilized to ascertain immediate answers or estimates of water quality associated impacts. There is a general lack of readily accessible methodology applicable to the water quality management problems.

2. Partial equilibrium models are not free of limitations but must be utilized in the short run.

3. Cost minimization is the preferred partial equilibrium approach in that it formulates the problem in its proper conceptual framework.

4. Other deficiencies or limitations such as the substitution phenomenon, current aggregation problems and the transformation function relating degree of treatment and resulting surface water quality, prevent and prohibit ascertaining socially optimum results.

The above items constitute the major methodological issues that have been encountered. These have been recognized in the preceding chapters and in some cases steps were initiated to partially eliminate the problems or at least to describe in more detail the considerations that are involved.

B. Benefit and Cost Estimation Conclusions

1. Pollution abatement cost estimates do not represent a pressing research need.

2. Water quality associated benefit estimation represents a pressing research need.

3. Benefit estimation methodology is currently lacking, especially in reference to intangible esthetic, recreation and ecological impacts.

4. Results of existing studies can not be accurately extrapolated to derive national benefit (cost reduction) estimates.

5. Pollution abatement standards do not appear justifiable based solely on monetary cost reductions. Other indirect and intangible costs need to be quantified.

6. The feasibility of national pollution abatement measures hinge almost entirely on recreation, esthetic and ecological cost reductions. It is felt that these beneficial uses are the source of sizeable benefit estimates or cost reductions and have not as of this time been adequately estimated primarily because of lack of appropriate methodology.

7. Given current benefit estimation techniques national benefits (cost reductions) are not expected to be of sufficient magnitude to justify pollution abatement expenditures (annualized costs).

8

8. The subjective benefit and cost material presented in Appendix A represents a first effort to establish a national priority with respect to beneficial use and specific pollutant and is viewed as possessing considerable value as a planning and decision tool.

The above items indicate that there are numerous shortcomings in benefit cost methodology and current estimates. This limitation stems primarily that previous work has been project-problem-crisis oriented. Few have attempted to identify and quantify national impacts of water quality improvement in methods other than extrapolating existing studies. This has left sizeable methodology and estimate voids, i.e., for example, even though a great deal is known about the harmful effects of specific pollutants, nowhere have we been able to find listings of specific pollutants according to the damage they inflict on a national basis. The problem-project-crisis approach leaves much to be desired in that national directions are left unspecified and are difficult to determine. One should not be overly pessimistic in that the recognition of the problem is the first step in the eventual solution. If Phase III could further refine the direction of future study or make even very minor inroads into the development of ecological, esthetic or recreational estimation research needs and procedures, the contributions of the project would be highly significant.

Before suggesting areas of emphasis for future research, it is perhaps again instinctive to place the problem in perspective by refocusing on the short-run and immediate research needs listed in Section I. These short-run and immediate research needs and priorities are reproduced below:

C. Short-Run Economic Research Needs and Priorities

The following items constitute economic research needs that could be at least partially satisfied in the short-run given existing data and methodology constraints. The three major divisions and subdivisions are listed in their relative order of importance.

It should not be surprising to find that benefit estimation is the singularly most important need to be satisfied in the short-run.

I. Develop, refine and implement methodology for assessing water quality associated impacts with special emphasis on the following short-run research needs.

  A. Benefit estimation
    1. Refinement of overall benefit estimation methodology
    2. Refinement and implementation of intangible benefit estimation methodology and techniques
    3. Estimation of substitution impacts
    4. Development of multivariate water quality associated benefit functions
    5. Interfacing economic, hydrologic, biological and engineering water quality models
    6. Estimation of irreversible damages
    7. Development of a satisfactory aggregation scheme.

  B. Cost estimation
    1. Refinement of overall cost of pollution abatement methodology
    2. Development of nonpoint pollution estimate and cost of treatment
    3. Development of a treatment versus resulting stream quality function
    4. Further development of least cost treatment strategies
    5. Development of cost aggregation framework

C. Implicit in all of the above items is the development of a satisfactory data base including but not limited to the following items.
  1. Pollutant level by receptor
  2. Effluent flows by source
  3. Effluent flows by process
  4. Precise water quality monitoring data
  5. Damage thresholds and impact ranges
  6. Critical effluent levels
  7. Synergistic effects

II. Develop pollution abatement policy alternatives with special emphasis on the following items:

  A. Development of spatially variable policies and abatement standards
  B. Minimization of equity and distribution effects
  C. Development of alternative policies to provide internal incentives to reduce effluent loads

III. Analysis and inauguration of institutional and structural changes required to implement many of the above items.

D. Immediate Research Needs and Priorities

While all of the above items constitute short-run economic research needs and priorities that could be eliminated given present data and methodology constraints, there is great disparity in the importance or urgency associated with each of these items. There is also the need to further develop and refine techniques useful in appraising short-run priorities so as to insure that current resources and efforts are properly directed. For this reason those items representing the greatest need have been singled out and listed below:

1. Continue to develop, refine and implement procedures useful in ascertaining the most detrimental pollutants.
2. Continued refinement of water quality associated benefit estimation methodology.
3. Development and implementation of benefit estimation methodology appropriate for the estimation of intangible water quality associated benefits.
4. Investigation of complex water quality substitution effects.
5. Development and implementation of multivariant benefit function (relating benefits to several key pollutants).
6. Interfacing economic, biological, hydrological and engineering models.

The areas recommended for immediate emphasis should be consistent with the areas representing the greatest current needs. The following items are therefore proposed possible areas of immediate emphasis and are consistent with the original areas of need.

I. Further development of general methodology applicable to assessing the impacts of water quality deterioration. Items of special interest may include attempts to explore selected methodological problems that are currently lacking and prohibit accurate water quality assessment.

    a. Substitution effects
    b. Treatment versus quality transformation functions
    c. Aggregation schemes

II. Additional refinement of benefit matrix material presented in Appendix A, with the expressed intent of achieving refined, final priority ranking to be used as a decision tool and general aid in providing direction for future research so that current efforts can be directed to those areas representing the greatest current need.

III. In that the justification of future pollution abatement investment seems to hinge on identification and quantification of ecological, esthetic and recreational impacts, any effort expended in this direction has a great potential value. The third alternative is therefore to devote time and effort to contribute to the development and refinement of associated methodological and estimation problems.

SECTION VII

APPENDICES

Page

A. Appraisal of Costs of Control and Benefit Estimates 126

B. Water Quality Associated Health Impacts 160

C. Specific Pollutants 175

D. Critical Levels and Damage Thresholds 185

APPENDIX A

Appraisal of Costs of Control and Benefit Estimates

State-of-the-Data
and
Subjective Estimates

One of the purposes of this Phase II report is to provide an insight into the current state-of-the-data with respect to costs of water pollution control and the pollution cost reductions (benefits) accruing therefrom. Also, this report is to address and provide subjective estimates of costs of control, relative magnitude of beneficial uses, and relative importance of specific pollutants. This appendix is dedicated to fulfilling these objectives.

Costs of Control - Introduction

In examining costs of abatement, the following items are relevant:

1. Total wastewater flow
2. Quality of untreated wastewater
3. Total wasteload before treatment
4. Treatment strategies employed
5. Proportion of wastewater that is treated
6. Quality of effluent after treatment
7. Total wasteload after treatment
8. Regional distribution of wasteflows

Each of these needs to be examined for each source group. Furthermore, it must be recognized that each item changes over time and, hence, the dynamic characteristics of the problem should be addressed. This latter point is especially critical in view of the current and anticipated rates of technological advancement in the water pollution control industry. Rates of change in population and economic activity are likewise important. Also, when interpreting abatement cost estimates, it should be recognized that enforcement of effluent standards may, in the long run, induce emitors to initiate structural changes resulting in reduced wasteflow or increased quality of raw effluent. In short, any objective data currently available are the result of partial analyses and must be regarded accordingly. With these qualifications in mind, objective data concerning the ten points listed above are presented below for estimated conditions in 1968 and 1976. Then, meaningful data and benefit estimations can be pursued.

The Environmental Protection Agency has divided pollution sources into seven major categories (1):

1. Municipal
2. Industrial and power plants
3. Federal installations
4. Agricultural and rural
5. Mining
6. Water resource development
7. Transportation.

Industrial sources have further been classified in accordance with SIC (standard industrial code) numbers. In discussing costs of abatement below, EPA's source classifications are utilized. However, wastewater flows and cost data are only presented for the first two categories due to the state-of-the-arts of the data and time constraints.

Before further pursuing cost and benefit estimates, the reader is forewarned that the data contained in this appendix were assembled on a best efforts basis. They are presented here not because we feel they are final answers nor, in some cases, even good estimates but, rather, because of an acute awareness of the need for such data on the part of the policy-makers involved in environmental protection decision-making processes. The tasks undertaken and summarized herein were substantial and, in many cases, unprecedented. In view of the awesome nature of the problem addressed, both monetary considerations and length of time devoted to the undertaking were far less than what would be required to provide answers with which we would feel comfortable. However, if the reader reminds himself of the potential pitfalls involved in deriving subjective estimates based upon very limited data and doing so in a very short time frame, we feel the results can be of highly significant value. To our knowledge, the rankings of both beneficial uses and pollutants by relative importance represent the first of their kind. We feel they represent a monumental first step toward establishing a water quality research program soundly based upon anticipated results rather than emotion or chaos.

Total Flows, Raw Effluent Quality and Total Wasteload

Estimated total wastewater flows by source group during 1968 are presented in Exhibit A-1. Industrial wastewater flows are for process water only. The exhibit also contains estimated total wasteload by major pollutant based upon the concentrations which are also shown. It is immediately obvious that wastewater flows vary substantially between source groups, suggesting that some source groups such as chemicals and allied products and primary metals may be far more significant from an environmental viewpoint than others such as electrical machinery, rubber and plastics and textile products. Total wasteloads of specific pollutants are also unevenly distributed between the source groups.

Exhibit A-1 should be viewed as incomplete in that several specific pollutants which may be of interest are not reported and data are not available in some instances for even the more commonly studied pollutants. Expansion of these tables to include all effluent quality characteristics adopted in Chapter V of this report should be considered as a priority area for further research. It should also be noted that the numbers reported in the tables are estimates and, in some cases, the validity of the estimates are at best questionable. Refining these estimates for 1976 conditions should be viewed as another research priority area.

Treatment and Effluent Quality

Since effluent characteristics vary by source group and even by process within a source group, different pollution abatement strategies are required by source group. For current purposes, the following treatment strategies are considered (1):

Exhibit A- 1. Raw wasteflows and pollutant loads by source group, 1968

Item	Food & kindred products	Textile mill products	Lumber & wood products	Paper & allied products	Chemical & allied products
Volumetric flow (billion gallons/year)	853	217	194	3,010	2,840
Concentration before treatment					
BOD (mg./ℓ)	750	760	NA	370	315
Total load (million lbs/yr)	5,340	1,375	NA	9,290	7,460
COD (mg./ℓ)	1,900	800	NA	3,500	400
Total load (million lbs/yr)	13,500	1,450	NA	89,000	9,430
Fecal coliform bacteria (10^6MPN/100 ml)	2.6	0	0	0	0
Total dissolved solids(mg./ℓ)	1,100	1,300	NA	NA	NA
Total load (million lbs/yr)	7,830	2,350	NA	NA	
TSS (mg./ℓ)	1,150	90	NA	190	62
Total load (million lbs/yr)	8,180	163		4,770	1,470
pH	7.2	8.0	NA	NA	NA
Toxic substances (mg./ℓ)	NA	20	-	NA	NA
Total load (million lbs/yr)	NA	36	-	NA	NA

continued.....

Exhibit A- 1. Raw wasteflows and pollutant loads by source group, 1968 (continued)

Item	Petroleum & coal	Rubber & plastics	Leather	Stone, clay & glass	Primary metals	Fabricated metal products
Volumetric flow (billion gallons/year)	430	62	51	240	1,820	110
Concentration before treatment						
BOD (mg./ℓ)	45	30	2,500	NA	15	NA
Total load (million lbs/yr)	161	15.4	1,070	NA	228	NA
COD (mg./ℓ)	200	60	3,000	NA	80	NA
Total load (million lbs/yr)	717	30.8	1,290	NA	1,214	NA
Fecal coliform bacteria	0	0	0	0	0	0
(10^6MPN/100 ml)	-	-	-	-	-	-
Total dissolved solids (mg./ℓ)	NA	0	30,000	NA	NA	NA
Total load (million lbs/yr)		0	12,800	NA	NA	NA
TSS (mg./ℓ)	42	37	2,000	NA	130	NA
Total load (million lbs/yr)	150	19	854		1,970	
pH	4.5	NA	NA	NA	NA	NA
Toxic substances (mg./ℓ)	NA	NA	NA	NA	NA	NA
Total load (million lbs/yr)	NA	NA	NA	NA	NA	NA

continued.....

Exhibit A- 1. Raw wasteflows and pollutant loads by source group, 1968 (continued)

Item	Machinery	Electrical equipment	Transportation equipment	Municipal Wastewater	
				Domestic	Industry not reported elsewhere
Volumetric flow (billion gallons/year)	99	139	160	6, 142	411
Concentration before treatment					
BOD (mg. /)	48	92	60	276	276
Total load (million lbs/yr)	40	107	80	14, 137	946
COD (mg. /)	NA	NA	NA	350	350
Total load (million lbs/yr)	NA	NA	NA	17, 930	1, 200
Fecal coliform bacteria (10^6MPN/100 ml)	0	-	-	200	200
Total dissolved solids(mg. /)	NA	NA	NA	700	700
Total load (million lbs/yr)	NA	NA	NA	35, 800	2, 400
TSS (mg. /)	40	26	NA	200	200
Total load (million lbs/yr)	33	30	NA	10, 250	685
pH	NA	NA	NA	NA	
Toxic substances (mg. /)	NA	NA	NA	NA	
Total load (million lbs/yr)	NA	NA	NA	NA	

Source: Volumetric flow: Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

Other data: DPRA subjective estimates.

1. Oil separation
2. Equalization
3. Coagulation and sedimentation
4. Neutralization
5. Floatation
6. Sedimentation
7. Aeration
8. Biological stabilization
9. Chlorination
10. Evaporation
11. Incineration
12. Activated sludge

By taking a combination of these treatment processes, one can generally describe the treatment strategy of a given source group. Exhibit A-2 represents such an undertaking. It is stressed that the strategies so depicted are generalized and may not be truly representative of each and every emitor within a given source group.

Historically, a large proportion of the total wasteflow was not treated. Even though significant inroads were made during the past decade, effluent treatment was not universally practiced by 1968. Exhibit A-3 contains estimates of the proportion of wasteflow treated by source group at that point in time. For the task at hand, it will be assumed that 100 percent of all point effluents will be treated by 1976.

Effluent quality after treatment by source group is very difficult to estimate. Some of the complicating factors are discussed in Chapter V of this report. They can be summarized by recognizing that within a given source group, different raw effluent qualities, specific treatment processes and operating policies, and climatic conditions will vary. Even so, after treatment effluent qualities are recognized as critical determinants in comparing benefits and costs accruing from alternative national pollution control policies. Therefore, our best estimate of after treatment quality under wasteflows and treatments prevailing in 1968 is presented in Exhibit A-4. However, the reader is warned that the estimates are subject to a very low degree of confidence due to very limited and conflicting data. Estimates are only presented for BOD, COD, and TSS since these appear to be the only pollutants consistently

Exhibit A- 2. Treatment processes employed to control specific pollutants, by source group to meet current standards in 1968*/

Pollutant	Food & kindred products	Textile mill products	Lumber & wood products	Paper & allied products	Chemicals & allied products
Biochemical oxygen demand	6, 8	6, 8	6, 8	6, 8, 11	6, 7, 8, 9
Chemical oxygen demand	3, 5, 6, 8	3, 6, 8	6, 8	6, 8, 11	1, 3, 5, 6, 7, 8, 9
Fecal coliforms	9	-	-	-	-
Dissolved solids	3	3	NA	NA	3
Suspended solids	3, 5, 6, 8	3, 6, 8	6, 8	6, 8, 11	3, 5, 6, 8
pH	2, 4	2, 4	4	4	2, 4
Toxic substances	NA	3, 6	6	6	3, 6

continued.....

Exhibit A- 2. Treatment processes employed to control specific pollutants, by source group to meet current standards in 1968*/ (continued)

Pollutant	Petroleum & coal	Rubber & plastics	Leather	Stone, clay & glass	Primary metals	Fabricated metal products
Biochemical oxygen demand	8, 12	6, 8	8	NA	6, 8	3, 9
Chemical oxygen demand	1, 3, 5, 8, 12	3, 6, 8	3, 5, 8	NA	1, 3, 6, 8	3, 9
Fecal coliforms	-	-	-	-	-	-
Dissolved solids	3	3	3	3	3, 10	3
Suspended solids	3, 5, 8	3, 6, 8	3, 5, 8	3, 6	3, 6, 8	3
pH	2, 4	2, 4	2, 4	4	2, 4	2, 4
Toxic substances	2	-	NA	NA	3, 6, 10	3

continued ....

Exhibit A-2. Treatment processes employed to control specific pollutants, by source group to meet current standards in 1968*/ (continued)

Pollutant	Machinery	Electrical equipment	Transportation equipment	Municipal wastewater
Biochemical oxygen demand	3	3, 9	3, 9	6, 8
Chemical oxygen demand	3	3, 9	3, 9	6, 8
Fecal coliforms	-	-	-	9
Dissolved solids	3	3	3	6, 8
Suspended solids	3	3	3	6, 8
pH	2, 4	2, 4	2, 4	NA
Toxic substances	3	3	3	-

*/ See text for definition of treatment process code numbers.

Source: Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

Exhibit A- 3. Municipal and industrial wastewater treatment practices in the U.S., 1968
Billion gallons of wasteflow by disposal method

Source	Treated by industry	Sewered, by treatment level			Ground discharge	Untreated	Total
		Primary	Secondary	Untreated			
Food and kindred products	204.5	89.8	155.8	23.4	49.4	330.0	853
Textiles	86.2	27.0	46.7	7.0	2.2	48.0	217
Lumber and wood products	39.6	1.8	3.0	0.5	8.0	141.0	194
Paper and allied products	1,326	35.2	61.1	9.2	24.1	1,559.0	3,010
Chemicals and allied products	457	40.7	70.6	10.6	28.4	2,232.0	2,840
Petroleum and coal	324	0.9	1.5	0.2	4.7	98.7	430
Rubber and plastics	3.3	3.6	5.2	0.9	1.2	46.3	62
Leather*	34.2	11.6	20.2	3.0	1.4	0	51
Stone, clay and glass	39.6	7.5	13.1	2.0	12.7	165.0	240
Primary metals	560	18.8	32.6	4.9	16.4	1,187.0	1,820
Fabricated metal products	12.2	21.8	37.9	5.7	0	32.4	110
Machinery	13.7	8.2	14.1	2.1	0	61.1	99
Electrical equipment	33	29.2	50.5	7.6	4.6	14.1	139
Transportation equipment	12.5	14.1	24.4	3.7	4	101.0	160
Domestic	--	2,051.0	3,556.0	534.0	--	--	6,142

*Industrial treatment plus sewerage exceeds total wasteflow for the leather industry.

Source: Distribution of sewered treatment, DPRA.
Other data: Environmental Protection Agency, The Economics of Clean Water, Vol. I and II, Washington, 1972.

Exhibit A-4. Subjective estimates of after treatment wasteloads prevailing in 1968, by source group

Source group	Million pounds per year		
	BOD	COD	TSS
Food and kindred products	2,713	7,297	4,015
Textile	514	600	69
Lumber and wood products	N.A.	N.A.	N.A.
Paper and allied products	5,260	47,624	2,575
Chemicals and allied products	6,055	7,768	1,250
Petroleum and coal	78	276	90
Rubber and plastics	13	27	16
Leather	131	181	90
Stone, clay and glass	N.A.	N.A.	N.A.
Primary metals	174	8,101	1,392
Fabricated metal products	N.A.	N.A.	N.A.
Machinery	31	N.A.	24.4
Electrical equipment	46	N.A.	12.0
Transportation equipment	61	N.A.	N.A.
Municipalities	5,097	8,343	3,102

reported on an after treatment basis. Quality of treated effluents by alternative abatement strategies should be viewed as another research area deserving attention.

Total wasteflow, treated effluent concentrations and total wasteloads under 1968 flow conditions and current standards are estimated in Exhibit A-5.

Distribution of Wasteflows

Regional distributions of industrial wasteflows are summarized in Exhibits A-6 and A-7. The former table shows, for each industry, the proportion of wasteflow discharged in each water use region. The latter table shows, for each region, the proportion of the regional wasteflow generated by each industrial sector.

Wasteloads Summarized

Before proceeding to costs of control estimates, a brief summary of the data in Exhibits A-1 through A-7 seems in order and, for brevity, is presented below in outline format:

1. The total raw wasteload of any given pollutant varies substantially by source group.
2. The relative importance of a specific pollutant varies substantially by source group.
3. Effluent treatment process requirements vary substantially between source groups and pollutants within source groups.
4. In 1965, the degree of treatment varied tremendously between source groups.
5. Pollutant wasteloads under prevailing 1968 conditions varied substantially by source group but, in general all sources were at relatively low levels of treatment. (We feel the data for the leather industry is misleading due to a high degree of overlap between private and municipal treatment leaving a substantial amount of low quality effluent).

Exhibit A- 5. Wasteflow, after treatment pollutant concentrations and after treatment wasteloads, current standards in 1968, by source group

Item	Food & kindred products	Textile mill products	Lumber & wood products	Paper & allied products	Chemical & allied products
Volumetric flow (billion gallons/year)	852	217	194	3,015	2,840
Concentration after treatment					
BOD (mg./ℓ)	35	35	NA	30	20
Total load (million lbs/yr)	250	63		754	474
COD (mg./ℓ)	50	40	NA	60	35
Total load (million lbs/yr)	355	72		1,510	829
Fecal coliform bacteria (10^6MPN/100 ml)	.09	-	-	-	-
Total dissolved solids (mg./ℓ)	900	1,100	NA	NA	NA
Total load (million lbs/yr)	7,000	2,000	-	-	
TSS (mg./ℓ)	40	20	NA	20	20
Total load (million lbs/yr)	285	36	-	503	474
pH	NA	NA	NA	NA	NA
Toxic substances (mg./ℓ)	NA	4	NA	NA	NA
Total load (million lbs/yr)		7			

Exhibit A- 5. Wasteflow, after treatment pollutant concentrations and after treatment wasteloads, current standards in 1968, by source group (continued)

Item	Petroleum & coal	Rubber & plastics	Leather	Stone, clay & glass	Primary metals	Fabricated metal products
Volumetric flow (billion gallons/year)	430	62	51	240	1, 820	110
Concentration						
BOD (mg./)	15	10	50	NA	5	NA
Total load (million lbs/yr)	54	5	21		76	
COD (mg./)	20	20	NA	NA	40	NA
Total load (million lbs/yr)	72	10			607	
Fecal coliform bacteria (10^6MPN/100 ml)	-	-	-	-	-	-
Total dissolved solids (mg./)	NA	NA	NA	NA	NA	NA
Total load (million lbs/yr)						
TSS (mg./)	20	15	40	NA	20	NA
Total load (million lbs/yr)	72	8	17		304	
pH	NA	NA	NA	NA	NA	NA
Toxic substances (mg./)	NA	NA	NA	NA	NA	NA
Total load (million lbs/yr)						

Exhibit A-5. Wasteflow, after treatment pollutant concentrations and after treatment wasteloads, current standards in 1968, by source group (continued)

Item	Machinery	Electrical equipment	Transportation equipment	Municipal wastewater
Volumetric flow (billion gallons/year)	99	139	160	7,480
Concentration after treatment				
BOD (mg./)	25	40	30	20
Total load (million lbs/yr)	21	46	40	1,250
COD (mg./)	NA	NA	NA	35
Total load (million lbs/yr)				
Fecal coliform bacteria (10^6MPN/100 ml)	-	-	-	6.7
Total dissolved solids (mg./)	NA	NA	NA	620
Total load (million lbs/yr)				3,870
TSS (mg./)	20	15	NA	20
Total load (million lbs/yr)	17	17		1,250
pH	NA	NA	NA	NA
Toxic substances (mg./)	NA	NA	NA	NA
Total load (million lbs/yr)				

Source: Volumetric Flows: Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

Other data: DPRA.

Exhibit A-6. Regional distribution of industrial waste discharge, by major industrial sectors, 1968

		PERCENT OF DISCHARGE OF INDUSTRY'S WASTEWATER, BY INDUSTRIAL WATER USE REGION																
	Regionally Assignable Discharge	New Eng.	Del. & Hud.	Chesa. Bay	East. Gr. Lak. St. Law.	Ohio Riv.	Tenn. Cum.	S.E.	West Gr. Lak.	Upper Miss.	Lower Miss.	Mo.	Ark. WBR	West. Gulf	Colo. Basin	Gr. Basin.	Cal.[1]	Pacf. N.W.[2]
Meat Products	99.0	.5	4.2	2.7	1.0	8.6	1.5	11.6	2.8	30.9	1.7	17.9	6.7	2.8	D	D	3.5	2.6
Dairy Products	98.8	7.5	4.3	4.9	8.9	5.1	.6	2.3	12.5	24.7	2.8	4.3	4.7	1.	D	1.3	7.0	6.4
Canned & Frozen Foods	93.1	1.4	3.2	2.5	3.9	2.3	D	29.0	5.3	2.9	1.9	.9	1.8	.8	D	D	20.5	16.7
All Other Food Products	84.4	3.7	5.9	.7	1.0	4.0	.2	3.4	9.8	14.0	11.7	6.7	.3	1.5	D	D	20.3	1.2
Textile Mill Products	98.5	13.5	4.7	2.9	.5	2.4	6.3	65.7	D	.5	1.4	--	D	D	D	D	.6	D
Paper & Allied Products	98.7	11.9	3.3	4.9	3.2	2.4	3.1	28.9	7.8	6.0	2.7	1.0	3.8	2.5	.1	D	2.1	15.0
Chemical & Allied Products	99.0	1.2	7.3	5.7	6.4	16.6	9.3	4.7	2.7	2.1	8.0	.4	.9	31.5	D	D	.6	1.6
Petroleum and Coal	92.0	.1	26.4	D	5.8	2.3	--	2.0	13.0	1.2	10.2	1.6	1.1	27.5	D	.1	8.4	.2
Rubber & Plastic, n.e.c.	92.9	15.8	7.4	2.5	35.7	6.8	D	6.9	8.4	4.3	3.3	D	.9	D	D	D	.9	D
Primary Metals	96.6	.7	6.1	6.9	17.5	29.4	.5	1.7	25.2	2.6	D	.4	.6	3.4	.2	D	.2	1.2
Machinery exc. Electrical	99.9	14.9	34.0	1.2	4.8	9.0	.8	.7	12.5	19.8	.3	.2	.3	.7	D	D	.7	D
Electrical Machinery	96.9	9.6	18.	10.8	8.5	25.6	1.0	4.1	9.0	5.	.5	.8	.9	D	D	D	3.0	D
Transportation Equipment	97.0	31.4	3.	5.1	33.3	4.6	.6	1.7	7.1	2.1	D	D	.5	5.0	D	D	2.2	D
Assignable Discharge	96.5	93.2	96.7	82.6	95.9	98.1	91.5	97.8	96.1	88.7	78.7	81.3	95.7	99.3	61.7	8.2	81.6	87.6
Percent of Industrial Discharge, 1968	100.0	3.9	8.3	5.3	10.2	16.1	3.8	7.7	12.7	4.1	5.2	1.0	1.3	13.3	0.1	0.2	2.8	4.0

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[1] Includes Hawaii

[2] Includes Alaska

D = Disclosure not available due to disclosure constraints on U. S. Bureau of Census

Source: Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

Exhibit A- 7. Sources of regional industrial waste discharge, by region, 1968

PERCENT OF REGIONAL DISCHARGE BY INDUSTRY

	New Eng.	Del.	Chesa Bay	East Gr. Lak.	Ohio Riv	Tenn. Cumb.	S.E.	West. Gr. Lak.	Upper Miss.	Low Miss.	Mo.	Ark. W&R	West. Gulf	Colo. Basin	Gr. Bas.	Cal.[1]	Pacf. N.W.[2]
Meat Products	.1	.4	.4	.1	.4	.3	1.0	.2	5.3	.2	12.5	3.6	.1	D	D	1.1	5
Dairy Products	.7	.2	.3	.3	.1	-	.1	.4	2.3	.2	1.6	1.4	-	D	2.6	1.2	6
Canned & Frozen Foods	.3	.6	.4	.3	.1	-	3.2	.4	.6	.3	.8	1.2	-	D	D	7.8	38
All Other Food Products	2.5	4.0	.5	.3	.8	.2	1.5	2.4	11.6	7.6	22.6	.7	.4	D	D	9.1	11
Textile Mill Products	3.3	.5	.5	-	.1	1.6	8.1	D	.1	.3	-	D	D	-	-	.3	D
Paper & Allied Products	44.1	5.8	13.4	4.5	2.1	11.8	54.6	9.0	21.4	7.7	14.3	42.7	2.7	D	-	14.1	585
Chemical & Allied Products	9.3	25.7	31.7	18.4	30.2	72.6	18.0	6.2	15.0	45.0	12.3	20.9	69.2	15.3	D	8.5	123
Petroleum and Coal	.1	26.9	D	4.8	1.2	-	2.3	8.7	2.5	16.6	13.6	7.4	17.6	D	5.6	32.4	5
Rubber & Plastic, n.e.c.	3.6	.8	.4	3.1	.4	-	.8	.6	.9	.6	D	.6	D	-	D	.4	D
Primary Metals	5.9	24.0	31.0	56.1	60.1	4.1	7.2	65.3	20.7	D	14.0	15.5	8.4	46.4	D	3.2	103
Machinery exc. Electrical	4.8	5.2	.3	.6	.7	.3	.1	1.2	5.2	.1	.3	.3	.1	D	D	.4	D
Electrical Machinery	2.0	1.8	1.7	.7	1.3	.2	.4	.6	1.0	.1	.6	.6	D	D	D	1.1	D
Transportation Equipment	16.5	.8	2.0	6.7	.6	.4	.5	1.1	1.1	D	D	.8	.8	D	D	2.0	D
Assignable Discharge	93.2	96.7	82.6	95.9	98.1	91.5	97.8	96.1	88.7	78.7	81.3	95.7	99.9	61.7	8.	81.6	876

D = Disclosure not available due to disclosure constraints on U. S. Bureau of Census

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[1] Includes Hawaii

[2] Includes Alaska

Source: Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

6. Our interpretations of current standards and associated wasteloads after treatment imply that current standards applied in 1968 would have greatly reduced the after treatment wasteload as compared to prevailing conditions at that time.

7. Although not estimated herein, wasteflows in 1976 under full compliance will still contribute sizeable pollutant loads to surface waters.

8. Regional wasteflows and composition of wasteflows are of such a nature that regional considerations in a national pollution control assessment cannot be ignored.

Costs of Control

Capital and annual operation and maintenance costs required to meet current standards in 1968 are presented in Exhibit A-8. These data are supplied by EPA (1) as the maximum possible cost. However, the costs are based upon prevailing water efficiency and wasteflow conditons in 1968. Also, from various industrial firms and trade organizations we have seen substantially higher estimates. We feel EPA's maximum cost number for 1968 is probably better than the ones assuming structural changes resulting in substantial increases in water use efficiency and modification of wasteflow levels.

For comparative purposes, the estimated replacement value of industrial and municipal treatment facilities are presented in Exhibit A-9. Again, the actual 1968 condition falls considerably below the current standards case. This condition is summarized in Exhibit A-10 which reports capital requirements in 1968 to meet current standards, prevailing 1968 treatment configurations and the amount that prevailing costs fell short of current standards. Also, the capital cost of meeting economic and population expansion between 1968 and 1976 are presented in the latter table. Please note that the 1976 capital requirements are stated in constant 1967 dollars and that the inflation rate for construction costs in the wastewater treatment segment of the economy has risen much more rapidly than for the economy on the average. Wastewater capital costs during 1968-71 rose roughly one-third. Total annual municipal and industrial pollution control costs for full compliance in 1976 (including annualized capital cost) will probably exceed 4.5 billion 1967 constant dollars.

Exhibit A- 8. Cost of meeting current standards under 1968 wasteflow conditions in millions of 1967 dollars

Pollutant treated/cost component	Food & kindred products	Textile mill products	Lumber & wood products	Paper & allied products	Chemicals & allied products
Biochemical oxygen demand					
Capital	781	216	163	1,170	434
Annual O&M	15	9	8	97	22
Chemical oxygen demand					
Capital	835	239	163	1,170	2,100
Annual O&M	22	10	8	97	112
Fecal coliforms					
Capital	4	0	0	0	0
Annual O&M	1	0	0	0	0
Dissolved solids					
Capital	40	23	N.A.	N.A.	350
Annual O&M	2	1	N.A.	N.A.	52
Suspended solids					
Capital	835	239	163	1,170	804
Annual O&M	22	10	8	97	102
pH					
Capital	158	13	23	381	338
Annual O&M	7	1	2	17	16
Toxic substances					
Capital	N.A.	149	91	490	475
Annual O&M	N.A.	8	6	58	61
Total cost					
Capital	997	251	186	1,551	2,436
Annual O&M	58	11	10	112	128

Exhibit A- 8. Cost of meeting current standards under 1968 wasteflow conditions in millions of 1967 dollars (continued)

Pollutant treated/cost component	Fabricated metal products	Machinery	Electrical equipment	Transportation equipment	Municipalities
Biochemical oxygen demand					
Capital	96	74	96	86	16,810
Annual O&M	9	8	11	12	629
Chemical oxygen demand					
Capital	96	74	96	86	16,810
Annual O&M	9	8	11	12	629
Fecal coliforms					
Capital	0	0	0	0	0
Annual O&M	0	0	0	0	2
Dissolved solids					
Capital	94	74	94	84	N.A.
Annual O&M	9	8	10	11	N.A.
Suspended solids					
Capital	94	74	94	84	16,810
Annual O&M	9	8	10	11	629
pH					
Capital	28	25	33	37	N.A.
Annual O&M	3	3	3	4	N.A.
Toxic substances					
Capital	94	74	94	84	0
Annual O&M	9	8	10	11	0
Total cost					
Capital	124	100	130	123	16,810
Annual O&M	13	11	14	16	631

Exhibit A-8. Cost of meeting current standards under 1968 wasteflow conditions in millions of 1967 dollars (continued)

Pollutant treated/cost component	Petroleum and coal	Rubber and plastics	Leather	Stone clay and glass	Primary metals
Biochemical oxygen demand					
Capital	650	71	27	N.A.	126
Annual O&M	24	4	1	N.A.	8
Chemical oxygen demand					
Capital	1,066	86	66	N.A.	1,240
Annual O&M	47	5	4	N.A.	126
Fecal coliforms					
Capital	0	0	0	0	0
Annual O&M	0	0	0	0	0
Dissolved solids					
Capital	84	16	38	136	473
Annual O&M	11	1	2	17	92
Suspended solids					
Capital	90	86	66	148	475
Annual O&M	11	5	4	17	99
pH					
Capital	30	10	21	34	258
Annual O&M	2	1	1	4	21
Toxic substances					
Capital	12	0	N.A.	N.A.	533
Annual O&M	00	0	N.A.	N.A.	96
Total cost					
Capital	1,096	96	87	182	1,620
Annual O&M	48	6	4	21	147

Source: Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

Exhibit A- 9. Cost of reported municipal and industrial treatment, 1968

Source Group	Cost in millions of 1967 dollars Capital replacement value	Annual operation
Food and kindred products	194	15
Textiles	49	4
Lumber and wood products	10	2
Paper and allied products	530	65
Chemical and allied products	343	63
Petroleum and coal	342	73
Rubber and plastics	3	0
Leather	17	2
Stone, clay and glass	20	2
Primary metals	216	35
Fabricated metal products	7	0
Machinery	15	1
Electrical equipment	24	2
Transportation equipment	17	1
Manufacturing	1,787	263
Municipal	12,392	539

Source: Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

Exhibit A- 10. Municipal and industrial waste treatment requirements, 1968 and 1976 capital cost, millions of 1967 dollars

Source group	Requirement 1968	Replacement value of capital supplied, 1968		Deficit 1968	Growth 1968-76	Requirement 1976
		Industrial	Municipal			
Food and kindred products	997	194	315	488	189	1,186
Textiles	251	49	64	138	82	333
Lumber and wood products	186	10	2	174	0*	186
Paper and allied products	1,551	530	79	942	145	1,696
Chemicals and allied products	2,436	343	192	1,901	572	3,008
Petroleum and coal	1,096	342	7	747	55	1,151
Rubber and plastics	96	3	23	70	38	134
Leather	87	17	17	53	18	105
Stone, clay and glass	182	20	22	140	27	209
Primary metals	1,620	216	126	1,278	560	2,180
Fabricated metal products	124	7	51	66	48	172
Machinery	100	15	49	36	5	105
Electrical equipment	130	24	92	14	34	164
Transportation equipment	123	17	92	14	13	136
Manufacturing	8,966	1,787	1,132	6,047	1,786	10,752
Municipal	16,810	N.A.	12,392	4,418	2,572	19,382

*Rate of improvement in water productivity is greater than rate of growth of output.

Source: Adapted from: Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

Benefits from Pollution Control

The reductions in national pollution costs (benefits) associated with the above costs of control data are not available at this time. However, some regional studies are available. Also, some subjective estimates as to the form of the national pollution cost reductions can be made. These are summarized below:

Exhibit A-11 represents a restatement of regional benefits obtained in three of the more comprehensive studies currently available. Note that the benefits are only referenced in terms of percentage distribution of monetary benefits accruing from pollution control among beneficial uses. Although the original studies reported actual dollar estimates, such estimates are not useful at this juncture since they cannot be used as a basis for estimates of absolute national welfare (see generally Chapters I-III of this report for substantiation of this conclusion).

Perhaps the most outstanding characteristic of these studies is representative of nearly all studies examining comprehensive benefits from pollution control -- empirical estimations of health, ecological and intangible esthetics are absent. Another problem is highlighted since none of the studies examine substitution effects. The Anondaga Lake study is further limited since it appears only one industrial firm of significant size in the area utilizes surface water as a supply and the municipal benefits were obtained by substituting water from one lake with water from another lake of equal quality. Municipal benefits were then calculated as the total cost of preuse treatment. Due to these shortcomings, the following discussion will consider only the Ohio and Maumee studies.

In apology to the original investigators, we readily admit that while we have stated benefit distributions in terms of a water quality range, they estimated benefits as a function of degree of effluent removal. Any interpretation errors resulting from this transformation rests solely upon those preparing this report and not the original investigators.

In search of a way to make the data in Exhibit A-11 take on more realism, it was felt an adjustment for substitution should be made -- at least for recreation. Since sources examining the magnitude of substitution effects in water-based recreation are not

Exhibit A- 11. Distribution of monetary benefits accruing from water pollution control among beneficial uses, selected studies, by level of water quality

Beneficial use	Ohio Basin		Maumee Basin		Onondaga Lake*/
	Low-medium water quality	Medium-high water quality	Low-medium water quality	Medium-high water quality	Medium-high water quality
Health	-	-	-	-	-
Production					
Municipal water treatment	2.6	3.3	24.2	28.9	12.8
Domestic use	6.3	8.0	31.7	25.4	-
Industrial use	6.9	8.8	13.9	21.6	3.5
Navigation	2.2	2.8	0.0	0.0	0.9
Commercial fishing	0.0	0.0	0.0	0.0	0.0
Total	18.1	23.0	69.8	75.9	17.3
Tangible esthetics					
Recreation	77.8	74.3	28.7	23.0	60.9
Property values	4.2	2.7	1.5	1.2	21.8
Total	81.9	77.0	30.2	24.1	82.7
Ecological and intangible esthetics	-	-	-	-	-
TOTAL	100.0	100.0	100.0	100.0	100.0

*/ Substantially revised by DPRA from originally published data so that meaningful comparisons could be made.

Sources: Ohio Basin: H. C. Bramer, The Economic Aspects of the Water Pollution Abatement Program in the Ohio River Valley, Doctoral Dissertation, University of Pittsburg, 1960.

Maumee Basin: Jack V. Matson, Cost of Industrial and Municipal Water Pollution Abatement in the Maumee River Basin, Master's Thesis, University of Toledo, 1968.

Onondaga Lake: N. L. Nemerow and R. C. Faro, "Measurement of the Total Dollar Benefit of Water Pollution Control," Benefits of Water Quality Enhancement, Environmental Protection Agency, Washington, 1970, pp. 39-144.

available, we hypothesized it could range anywhere from 0 to 100 percent. As a midpoint, we assumed 50 percent of the original benefit estimation for recreation would be lost due to substitution effects. The adjusted benefit distributions under this assumption are depicted in Exhibit A-12. Even then, recreation comprises a very large share of total benefits. These relationships for the Ohio and Maumee basins have been averaged and displayed geographically in Exhibit A-13.

The curves in Exhibit A-13 are interesting not only in terms of magnitudes but also in terms of slope. Simply stated, they imply that as water quality changes, beneficial uses are impacted in different proportions.

Utilizing the Ohio and Maumee studies as a base, subjective benefit distributions were derived which included both health and ecological and intangible esthetic impacts. First, the two studies were averaged and it was assumed the result is fairly representative of the U. S. as a whole. Secondly, recreation benefits were reduced 50 percent, as noted above, to adjust for substitution. Estimating ecological and intangible benefits were most difficult. After considerable deliberation, it was concluded that the best indicator for the value of these benefits was recreation benefits before substitution considerations. For current purposes we feel it is reasonable to assume that ecological and intangible benefits are at least as large as the receratational benefits as calculated in the base studies. Given production, tangible esthetics and ecological and intangible esthetic estimates, health benefits were estimated through observation of national health data and a good deal of subjectivity. A further subjective modification was required to include irrigation which was not a beneficial use in the base studies. The resultant estimates are presented in Exhibit A-14. The high proportion of benefits allocated to each category will no doubt be criticized by some as being too high and by others as being too low. Yet, we feel they are reasonable and accurately reflect the evidence presented by available studies. Note that the study team attempted to find documented evidence of such relationships but hypothesized any existence of such relationships for those cases where adequate documentation was not available.

To further investigate the importance of specific pollutants by beneficial use, the potential damages matrix in Exhibit A-15 was

Exhibit A- 12. Adjusted distribution of monetary benefits accruing from water pollution control among beneficial uses, by level of water quality*/

Beneficial use	Ohio Basin		Maumee Basin		Onondaga Lake*/
	Low-medium water quality	Medium-high water quality	Low-medium water quality	Medium-high water quality	Medium-high water quality
Health	-	-	--	-	-
Production					
Municipal water treatment	4.2	5.2	28.3	32.7	18.4
Domestic use	10.3	12.7	37.0	28.7	-
Industrial use	11.4	14.0	16.2	24.4	5.1
Navigation	3.7	4.5	0.0	0.0	1.3
Commercial fishing	0.1	0.1	0.0	0.0	0.0
Total	29.6	36.7	81.5	85.7	24.9
Tangible esthetics					
Recreation	63.6	59.1	16.8	13.0	43.8
Property values	6.8	4.2	1.7	1.3	31.4
Total	70.4	63.3	18.5	14.3	75.1
Ecological and intangible esthetics	-	-	-	-	-
TOTAL	100.0	100.0	100.0	100.0	100.0

*/ Assumes 50 percent of recreation benefits are eliminated when substitution impacts are included in the analysis.

Exhibit A-13. Average adjusted monetary benefit distribution for the Ohio and Maumee basins.

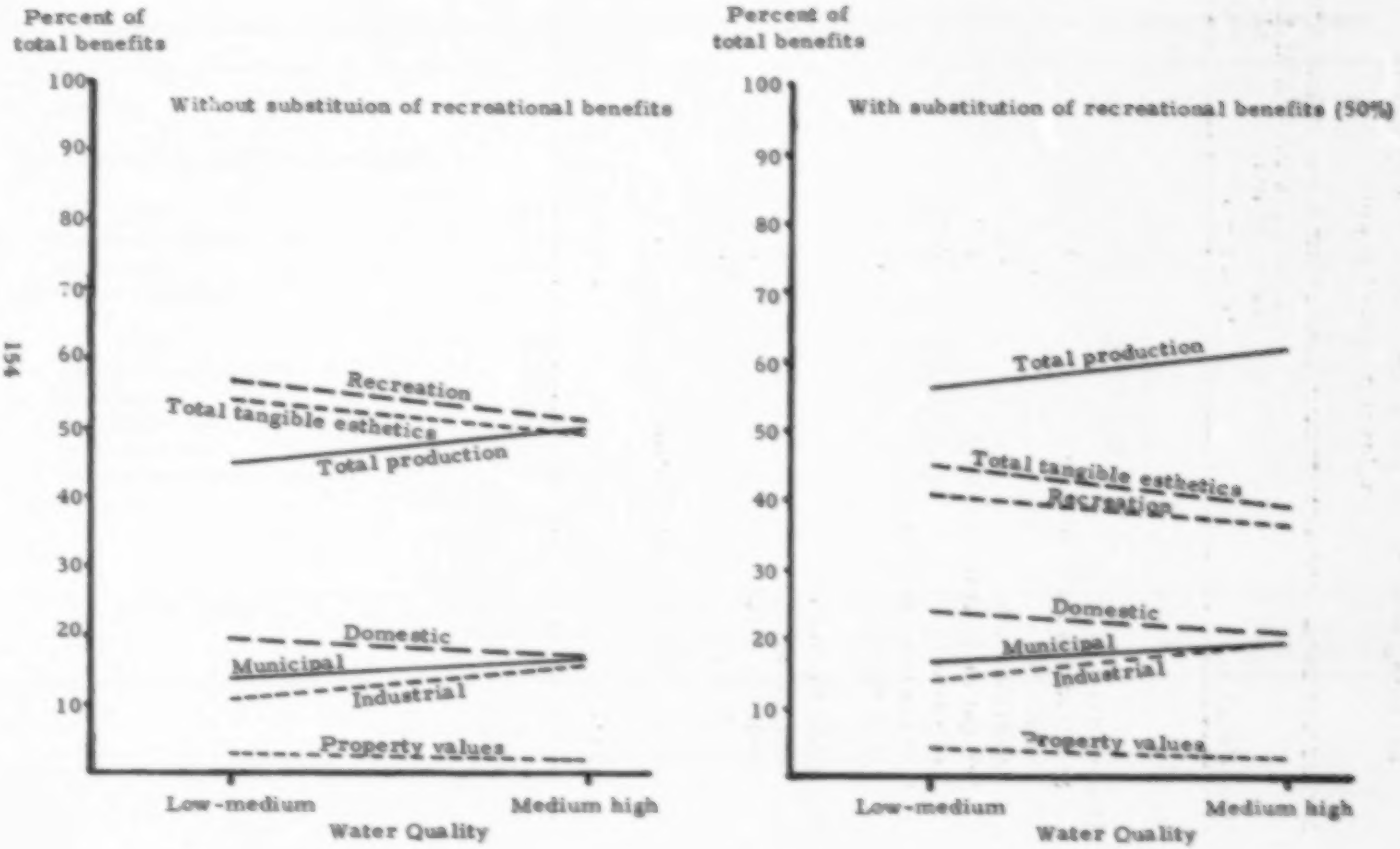

Exhibit A- 14. Subjective estimate of distribution of social benefits accruing from water pollution control among beneficial uses; by level of water quality

	% of Benefits	
Beneficial use	Low-medium water quality	Medium-high water quality
Health	4.5	4.0
Production		
Municipal water treatment	10.0	12.0
Domestic use	14.0	12.5
Industrial use	8.5	11.5
Irrigation & animal health	4.0	3.0
Navigation	0.5	1.5
Commercial fishing	0.1	0.1
Total	37.1	40.6
Tangible Esthetics		
Recreation	18.5	17.0
Property values	2.0	1.5
Total	20.5	18.5
Ecological & Intangible Esthetics	37.9	36.9
TOTAL	100.0	100.0

Exhibit A-15. State-of-the-arts of pollution-beneficial use potential relationships, over all ranges of water quality

	HEALTH	PRODUCTION																ESTHETICS				ECOLOGICAL
								Industrial											Recreation			
								(20)	(22)	(24)	(26)	(28)	(29)	(30)	(31)	(32)	(33)					
	Human Health	Mun. Prouse Treatment	Domestic Uses	Ag. Irrigation	Commercial Fishing	Power Generation	Navigation	Food and Kindred Prod.	Textile Mill Products	Lumber and Wood Prod.	Paper and Allied Prod.	Chem. and Allied Prod.	Petroleum & Coal Prod.	Rubber and Plastics	Leather	Stone, Clay and Glass	Primary Metals	Esthetic En-joyment	Non-contact	Contact	Property Values	
BOD	0U	1D	0U	1D	1D	1D	1U	1D	0D	0U	0U	0D	0U	0D	0U	0D	1D	1D	1D	1D	1D	1D
COD	0U	1D	0U	1D	1D	1D	1U	1D	0D	0U	0U	0D	0U	0D	0U	0D	1D	1D	1D	1D	1D	1D
pH	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	0D	1D	1D	1U	1D
Coliform	1D	1D	0U	1D	1D	0U	0U	1D	0U	0U	0U	0U	0U	0U	1D	0D	0U	1D	1D	1D	1U	1U
Nitrogen	1D	1D	0U	1D	1D	0D	1U	1D	0U	0U	0D	1D	0D	0D	0U	0U	0U	1U	1D	1D	1D	1D
Phosphate	0U	1D	0U	0U	1D	0U	1U	1D	0U	0U	0U	1U	0U	0U	0U	0U	0U	1D	1D	1D	1D	1D
Toxic Sub.*/	1D	1D	1D	1D	1D	0U	0U	1D	1U	0U	1D	1U	1U	1U	1D	1U	1U	0D	1D	1D	1U	1D
Hardness	1D	1D	1D	1D	1D	1D	1D	1D	1D	0U	1D	1D	1D	1D	1D	0D	1D	0D	0D	0U	0U	1D
TDS	1D	1D	1D	1D	1D	1D	1U	1D	1D	1U	1D	1D	1D	1D	1D	1D	1D	0D	1U	1U	1U	1D
TSS**	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1D	1U	1D	1D	1D	1D	1D	1U	1D
Temperature	0U	0U	1D	1D	1D	0D	0U	0D	1U	0U	1D	0D	1U	0U	0U	0U	1U	0D	1D	1D	1U	1D
Oil	1D	1D	1D	1D	1D	1D	1D	1D	1D	0U	1D	1D	0U	1U	1U	1U	1D	1D	1D	1D	1U	1D
Color	0U	1D	1D	0U	1D	1D	0U	1D	1D	1D	1D	1D	0D	1D	1D	0D	0U	1D	1D	1D	1U	1U
Turbidity	1D	1D	1D	0U	1D	1D	0U	1D	1D	1D	1D	1U	1D	1D	1D	0U	0U	1D	1D	1D	1D	1D
Odor	0D	1D	0U	0U	1D	0D	0U	1D	0D	0U	0U	0D	0U	0D	0U	0U	0U	1D	1D	1D	1D	1U
Taste	0D	1D	0U	0U	1D	0U	0U	1D	0U	0U	0U	0U	0U	0U	0U	0U	0U	0U	0D	1D	0U	1U
Radionuclea	1D	1D	0U	1D	1D	0U	0U	1D	0U	0U	0U	0U	0U	0U	0U	0U	0U	1D	1D	1D	1U	1D
Floating Solids	0U	1D	1U	0D	1D	0U	1D	1D	1U	1U	1U	1U	1U	1U	1U	1U	1U	1D	1D	1D	1D	1U

*/ Includes heavy metals.

**/ Includes settable solids.

1 => pollutant has an effect upon usability

0 => pollutant has no effect upon usability within water quality ranges normally encountered

D => a pollutant-use relationship has been documented

U => documentation of a pollutant-use relationship (or lack of one) has not been found, but such a relationship (or lack of one) seems plausible

References: 1. "Water Quality Criteria," FWPCA, 1968.
2. Todd, "The Water Encyclopedia," 1970.
3. "Manual on Industrial Water and Industrial Waste Water,", ASTM Special Technical Publication No. 148-I, 1966.
4. Zajic, J. L., "Water Pollution--Disposal and Reuse," 1971.
5. Lund, H. F., "Industrial Pollution Control Handbook," 1971.
6. "Cleaning our Environment the Chemical Basis for Action," Am. Chem. Soc. 1969.

Acknowledgement: Dr. Dennis Tihansky, Economic Analysis Branch, EPA, provided invaluable assistance in the preparation of the benefit matrix.

multiplied by the average of the appropriate beneficial use distributions in Exhibit A-14. The resultant subjective ranking is presented in Exhibit A-16. In most cases the individual cell values seem plausible. Also the ranking of beneficial uses based upon the average row seems consistent with anticipated results. However, the row (pollutant) ranks are not realistic. The problem here is hopefully one of not including indicators of pollutant and prevalence and intensity rather than basic inconsistencies in the ranking matrix.

Hence, our subjective ranking of beneficial uses is the order in which they appear in Exhibit A-16 with ecological and intangible esthetics being the most important. Commercial fishing is the least important.

One last step was taken to subjectively estimate the relative importance of specific pollutants. By adjusting the row rankings in Exhibit A-16 by subjective prevalence and intensity factors, a final ranking was obtained and summarized in Exhibit A-17. It should be noted that these rankings were made with respect to man-made pollutants. Impacts from natural pollution are not reflected in the rankings. However, we have attempted to account for both source point and non-point pollution in both the subjective benefit distributions and pollutant rankings.

At the risk of redundancy, we again point out that these data are highly subjective. The subjective rankings of pollutants are especially weak in that respect. However, it is our hope that they may be useful to those faced with allocating funds for future studies.

Exhibit A-17. Subjective ranking of specific pollutants by their relative impact on beneficial uses

Group I:	Organics -- BOD, COD
Group II:	Nutrients -- nitrogen and phosphates
Group III:	Suspended and dissolved solids
Group IV:	Turbidity, pH, temperature
Group V:	Fecal coliforms, oil, toxic substances, floating solids, color, odor
Group VI:	Hardness, taste radioactivity

Exhibit A-16. Subjective ranking of beneficial use-pollutant soical cost potential relationships[1]

Pollutant	Beneficial Use										
	Ecologic & intangible esthetics	Recre- ation	Municipal preuse treatment	Domestic use	Industry Use	Health	Ag. Irri- gation	Property values	Navi- gation	Com- mercial fishing	Total[2]
TSS	.374	.1775	.11	.1325	.10	.0425	.035	.0175	.01	.001	1.000
Oil	.374	.1775	.11	.1325	.08	.0425	.035	.0175	.01	.001	.980
Turbidity	.374	.1775	.11	.1325	.08	.0425	0	.0175	0	.001	.935
Floating solids	.374	.1775	.11	.1325	.10	0	0	.0175	.01	.001	.922
Color	.374	.1775	.11	.1325	.07	0	0	.0175	0	.001	.882
TDS	.187	.1775	.11	.1325	.10	.0425	.035	.0175	.01	.001	.813
pH	.187	.1775	.11	.1325	.10	.0425	.035	.0175	.01	.001	.813
Toxic sub.[3]	.187	.1775	.11	.1325	.09	.0425	.035	.0175	0	.001	.793
Nitrogen	.374	.1775	.11	0	.02	.0425	.035	.0175	.01	.001	.788
Coliform	.374	.1775	.11	0	.02	.0425	.035	.0175	0	.001	.778
Radionucles	.374	.1775	.11	0	.01	.0425	.035	.0175	0	.001	.768
COD	.374	.1775	.11	0	.02	0	.035	.0175	.01	.001	.745
BOD	.374	.1775	.11	0	.02	0	.035	.0175	.01	.001	.745
Phosphate	.374	.1775	.11	0	.02	0	0	.0175	.01	.001	.710
Odor	.374	.1775	.11	0	.01	0	0	.0175	0	.001	.690
Hardness	.187	0	.11	.1325	.08	.0425	.035	0	.01	.001	.598
Temperature	.187	.1775	0	.1325	.04	0	.035	.0175	0	.001	.590
Taste	.187	.0888	.11	0	.01	0	0	0	0	.001	.397
Total	5.610	2.9288	1.870	1.325	.970	.425	.420	.280	.100	.018	
Average	.312	.163	.104	.074	.054	.024	.023	.016	.006	.001	.793
Density[4]	.833	.917	.944	.556	.539	.556	.667	.889	.556	1.000	

[1] Cell rank equals product of row rank and column rank. Row rank is determined by distribution of total social benefits among beneficial uses. Column rank equals one if pollutant is significant for that use, otherwise zero. Maximum possible cell rank is 1.0.

[2] Maximum possible total value is 1.0.

[3] Includes heavy metals.

[4] Density = average value for column/highest possible value for a cell in that column.

References Cited

1. Environmental Protection Agency, The Economics of Clean Water, Vols. I and II, Washington, 1972.

2. Bramer, H. C., The Economic Aspects of the Water Pollution Abatement Program in the Ohio River Valley, Doctoral Dissertation, University of Pittsburg, 1960.

3. Matson, Jack V., Cost of Industrial and Municipal Water Pollution Abatement in the Maumee River Basin, Master's Thesis, University of Toledo, 1968.

4. Nemerow, N. L. and Faro, R. C., "Measurement of the Total Dollar Benefit of Water Pollution Control," Benefits of Water Quality Enhancement, Environmental Protection Agency, Washington, 1970, pp. 39-144.

APPENDIX B

Water Quality Associated Health Impacts

Phase I of this project included a brief section on the health impacts emanating from water quality degradation. This general area represents one are of water quality management which has received some attention in the past but complete documentation is presently lacking. The intent here is to briefly explore these water quality impacts, present data sources, procedures, and to so far as possible hypothesize the magnitude of water quality associated health impacts.

The Extent of the Health Impacts

There is substantial and convincing evidence of undesirable impacts on human health resulting from lack of water quality control. Microbiological, chemical, physical and radioactive pollutants are of concern with respect to human health. It has been estimated that in some countries one-third to one-half of the hospital beds are occupied by patients suffering from waterborne diseases (1).

A review of water-related disease outbreaks in the United States has shown that during the fifteen year period 1946-1960, there were 228 known outbreaks of disease attributed to drinking water. To be considered an outbreak, a death or at least two cases of the disease had to be reported. Thus the resulting statistics do not include single cases of waterborne diseases. The data show 25,984 cases of illness associated with waterborne diseases that occurred during the period. This gives an annual rate of 1.1 waterborne illnesses per 100,000 population served by public water supplies (2).

This rate includes outbreaks of typhoid, gastroenteritis, infectious hepatitis, salmonellosis and a few other diseases. However, it does not include methemoglobinemia, for example, since this usually occurs in individual cases of infants. There are some other human health impacts associated with water quality which have only recently come to attention of health officials. There are also many cases of water related health problems which are not reported by the victim as well as long-term effects which may occur over a number of years which have not yet been adequately analyzed. Thus the annual rate mentioned above of 1.1 waterborne illnesses per 100,000 population must be considered the lowest possible rate for that period (1946-60). Exhibit B-1 presents the incidence of water borne diseases in the U.S. during this period.

Exhibit B-1. Waterborne diseases in the United States, 1946-60

Disease	Outbreaks	Cases
	Number	Number
Gastroenteritis	126	13,630
Typhoid	39	506
Infectious hepatitis	23	930
Diarrhea	16	5,160
Shigellosis	11	5,653
Salmonellosis	4	24
Amebiasis	2	36
Other	7	45
Total	228	25,984

Source: The Nation's Water Resources, United State Water Resource Council, Washington, D. C., 1968. p. 5-4-1.

Major Water Quality Variables Associated with Health Impacts

The water quality variables currently being measured in the United States which are known to be most important in terms of health impacts are the levels of fecal coliforms, the biochemical oxygen demand (BOD), the dissolved oxygen level (DO), dissolved solids and levels of toxic chemicals such as mercury.

Biochemical oxygen demand is a surrogate indicator of the effect of a combination of substances and conditions. It is a measure of the amount of dissolved oxygen that will be depleted from the water during the natural biological assimilation of organic pollutants. Swiftly moving streams have a greater capacity, for reaeration and for preventing the accumulation of high BOD materials in bottom deposits than do sluggish streams or reservoirs.

Dissolved oxygen is one of the most commonly used parameters of water quality. Low levels of DO adversely affect fish and other aquatic life and total absence of DO leads to the development of an anaerobic condition with attendant odor and esthetic problems. The ability of water to hold DO decreases with increases in temperature or dissolved solids (3).

Fecal coliform counts show the level of fecal contamination of water. These counts are used as indicators of the potential of the water for transmission of viral diseases.

Levels of chemicals in water can often be measured directly.

Health Impacts Associated with Specified Pollutants

The following Exhibit (Exhibit B-2) presents a number of health impacts resulting from lack of water quality control, the method of transmission to the population, the specific pollutants involved in each impact and the sources of these pollutants. The most appropriate water quality variables which are currently thought to be reliable indicators of the potential of the water for transmission of the pollutant and creation of undesirable health impacts, or spreading of diseases (such as virus diseases) are also given.

Exhibit B-2

Methods of Transmission of the Pollutants to the Population

The methods of transmission of the pollutants to the population may be categorized as:

1. Pollutants which enter throug the public water supply.
   a. Chemical impurities
   b. Bacteria, viruses, etc.

2. Pollutants which enter through the food supply (where the food is polluted by water, such as a buildup of chemicals in fish which will be consumed by humans).
   a. Chemicals in water supplies
   b. Bacteria and viruses in water supplies

3. Effects of polluted water on transmission of communicable diseases by
   a. Natural populations (such as mosquitoes)
   b. Domesticated animals
   c. Humans

4. Pollutants which enter the body through direct (bodily) contact with the water.

5. Pollutants which lead to ecological changes which affect human physical and/or psychological health.

Health impacts (Damages)	Method of Transmission	Pollutants	Indicator (Water Quality Variable)	Source of Pollutant
Alteration of liver function, hydropericardium (accumulation of fluid in sac surrounding heart) and chloracne (skin eruptions).	(2) Through the food chain as PCB */	Polychlorinated biphenyls	PCB level (measured directly)	Industrial and municipal discharges to inland and coastal waters.
Eye irritation	(4) Bodily contact with water	Too high or low a pH level (and buffer capacity of water)	pH level (measured directly)	Discharges of acids or bases, acid mine drainage
Schistosomiasis-(rash stomach pain, dizziness, damage to internal organs, anemia, cancer of the liver)	(1) Enters through the intestine when person drinks contaminated water, and (4) Enters through the skin of swimmers or waders in contaminated water.	Schistosomiasis eggs in feces from infected humans develop into larvae in streams or ponds and seek an Australorbis glabratus snail. They burrow into the snail and emerge as free, swimming organisms which can infect man if a victim is found within 30 to 36 hours.	Coliform count - (Can be used as an indicator of the potential for transmission)	Human feces

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*/ Number codes in this column refer to categories described on page 4 of this section.

Health impacts (Damages)	Method of Transmission	Pollutants	Indicator (Water Quality Variable)	Source of Pollutant
Hepatitis (inflamation of liver)	(16, 26) a virus which is spread through contaminated water on food (esp. raw oysters or clams)	Virus growing in polluted water	Coliform count (is used as an indicator of potential for transmission of virus)	Human feces contaminated garbage
Cholera (diarrhea, vomiting, muscle cramps, low blood pressure)	(1b, 2b) through water supply or food supply, ingestion of food or water contaminated with V. cholerae	Contamination of supply with V. cholerae (through fecal contamination)	Coliform count	Human feces
Malaria (fever, chills, back pain)	(3) Transmitted by Anopheles mosquitoes	Mosquitoes breeding in swampy areas	Dissolved oxygen BOD Phosphates (alga growth is faster)	(Stagnant water) for ex. alga growth which stabilizes water surface

Health impacts (Damages)	Method of Transmission	Pollutants	Indicator (Water Quality Variable)	Source of Pollutant.
Leptospirosis (fever, muscular pain, nausea)	(4) Bodily contact with water	Microscopic parasites - leptospira	Coliform count	Urine of infected animals
Salmonellosis (stomach upsets, diarrhea, chills, fever)	(1b) 2b) contaminated water or food supply	Salmonellae bacteria which breed in food or water	Coliform count	Garbage, human feces
Minamata disease (mercury poisoning) (weakening of muscles, loss of vision, paralysis, coma death)	(2a) food chain such as in fish, methyl mercury is concentrated in food chains because it is fat soluble.	Mercury (Primarily in the form of methyl mercury)	Measure mercury directly in water (or fish)	Industrial discharges

Health impacts (Damages)	Method of Transmission	Pollutants	Indicator (Water Quality Variable)	Source of Pollutant
Renal effects itai - itai possibly hypertension (cadmium effects both acute and chronic) (cancer has been produced in animals)	(2a) - through the food chain	Cadmium	Measure cadmium	Industrial discharges
Methemoglobinemia (reduces ability of the blood to transport oxygen)	(1a) - through water supply	Nitrites and nitrates	Measure nitrites and nitrates directly	Industrial discharges and agricultural runoff
Endemic fluorosis dental and skeletal (chronic toxic effects on tooth enamel and bones; increased density of bone, stiffness of spine, limitation of movement)	(1a) through water supply (also food supply)	Fluoride	Measure fluoride directly	Fluoride is naturally occurring in water. (However this level may be increased by additional fluorides in the atmosphere (such as from gaseous industrial wastes) acting to increase the fluoride level of rain or precipitation)

Health impacts (Damages)	Method of Transmission	Pollutants	Indicator (Water Quality Variable)	Source of Pollutant
Amoebic dysentery - acute effects (even death)	(1-b) Water supply	Endomebia histolytic cysts	Coliform count	Human feces
Kidney stones	(la) Water supply	Dissolved solids	Dissolved solids	Industrial discharges irrigation return flows
Coronary heart disease and cardiovascular disease	(la) Water supply	Hardness of the water	Hardness of the water	Naturally occurring plus industrial pollution

Health impacts (Damages)	Method of Transmission	Pollutants	Indicator (Water Quality Variable)	Source of Pollutant
Offensive tastes and odor - both an esthetic and toxicological effect may result from the substances	(1) Water supply	Insecticides and organic compounds (for ex. phenols)	Taster-panels are used and analytical isolation techniques, that have been considered for taste-and-odor study of water include distillation and a carbon adsorption method	Insecticides from agricultural sources and trace trace organics and chemical compounds (from industrial discharges?)

Possible Procedures and Data Sources

In order to evaluate adequately the major health impacts (and the costs) associated with water quality degradation in the United States, the following tasks will have to be completed:

1. Data concerning the incidence, location, morbidity and mortality rates of the major diseases which are believed to be related to water quality will be collected from health statistics published by the Public Health Service and other sources. Representative sources of data on water-related diseases are:

   (a) Morbidity and Mortality; Weekly Report, Center for Disease Control, Atlanta, Ga., U.S.D.H.E.W. Vol. 20, No. 53, Annual Supplement, Summary, 1971.

   This is the most recent yearly summary in a series. It gives the reported incidence of notifiable diseases in the United States for 1962-1971, the deaths from specified notifiable diseases for 1959-1968 and deaths from selected non-notifiable acute diseases for 1959-1968. Cases of diseases are also reported by month and by geographic region and state.

   (b) Morbidity and Mortality: Weekly Report, Center for Disease Control, Atlanta, Ga., U.S.D.H.E.W., Vol. 21, No. 42 (for week ending October 21, 1972).

   This is a weekly report which can be used to obtain current data on incidence of notifiable diseases.

   (c) Weibel, S.R., Dixon, F.R., Weidner, R.B. and McCabe, L.J. Waterborne-Disease Outbreaks, 1946-1960, Journal of the American Water Works Assoc., 56, 947, (1964)

   (d) Hepatitis Surveillance, Report No. 19, Communicable Disease Center, June 30, 1964.

   (e) Shigella Surveillance, Report No. 26, Center for Disease Control, April, 1971.

2. Methods of assessing the incidence of various diseases over time as related to specific water quality variables must be developed.

   (a) Plots of the number of cases of these water-related diseases vs time may be constructed to show trends in such diseases over a time period (perhaps the last ten years).

   (b) Plots of appropriate water quality variables (for example, the coliform count, see below) which are considered reliable indicators of specific disease-associated variables vs time will be constructed and then shown on the same graphs. These graphs can be done for specific locations in the United States as well as for the nation as a whole.

   (c) Correlation or multiple regression analysis of incidence of diseases and water quality variables can be used to establish relationship between disease incidence and water quality. For example, the coliform count can be used as an indicator variable for diseases such as hepatitis. As a first approximation the virus concentration may be assumed to be directly proportional to the coliform count. This is the logical assumption to make in relating surface water quality to number of infectious hepatitis cases (7).

   (d) Sources of water quality variable data which can be used are:

      (1) Storet, Storage and Retrieval System for Water Quality Data, Environmental Protection Agency, 1972.

      (2) Water Resources Data for Kansas (also available for other states, Part 2. Water Quality Records, United States Department of the Interior. Geological Survey, (1967).

      (3) Water Pollution Surveillance System, Annual Compilation, Public Health Service, D.H.E.W., Volumes available for 1957-58 through 1962-63.

3. Costs associated with specific water-related diseases will be estimated. Both direct and indirect costs of illnesses will be considered. These costs include work-days lost, medical care costs and such intangibles as pain and suffering and disruption of family life and goals. Other considerations such as the economic cost of mortality rates associated with these diseases must also be included. (See references 8 and 9). Estimates of marginal costs or damages will be made wherever appropriate data is presently available. Where a strong correlation between a water quality variable and a specific health effect is found, the health costs associated with that effect will be related to the specific water quality variable to obtain marginal costs.

Summary

While there is substantial evidence relating to various diseases and adverse health impacts in general, to drinking water quality, many studies have indicated that many of these impact initiate from untreated groundwater or inadequate control of present treatment strategies. Exhibit B-4 presents the percentage distribution of sources of water borne diseases in the United States, 1946-1960. This summary would seem to indicate that proper surveillance of present treatment strategies and perhaps chlorination of currently untreated sources is the least cost treatment strategy.

Exhibit B-4. Percentage distribution of sources of waterborne disease in the United States, 1946-60

Source	Outbreaks	Cases
	Percent	Percent
Untreated surface water	9.6	3.2
Untreated ground water	41.7	33.9
Contamination of reservoir or cistern	1.3	0.7
Contamination of collection or conduit system	3.1	4.6
Inadequate control of treatment	15.4	41.4
Contamination of distribution system	16.7	12.9
Miscellaneous	12.2	3.3
Total	100.0	100.0

Source: The Nation's Water Resources, United States Water Resources Council, Washington, D. C., 1968., p. 5-4-1.

References Cited

(1) la Riviere, J.W.M.: American ociety for Microbiology 72nd annual meeting, April 25, 1972, Philadelphia, Pa., American Microbiology Society News, 38, No. 10: 536, 1972.

(2) Weibel, S.R., Dixon, F.R., Weidner, R.B. and McCabe, L.J.: Waterborne-disease outbreaks, 1946-1960, Journal of the American Water Works Association, 56: 947-958, 1964.

(3) Dee, Norbert et al.: Environmental Evaluation System for Water Resource Planning, Bureau of Reclamation, U.S. Dept. of Interior, January, 1972.

(4) Morbidity and Mortality Weekly Report, Center for Disease Control, Vol. 21, No. 31: p. 263-4.

(5) Shigilla Surveillance, Fourth quarter, 1970, Center for Disease Control, Report No. 26, April, 1971.

(6) Morbidity and Mortality, Weekly Report, Center for Disease Control, p. 379, November 4, 1972.

(7) Journal of Sanitary Engineering Division, American Society of Civil Engineers, 96:121, February, 1970.

(8) Rice, Dorothy P. Estimating the Cost of Illness, Health Economics Series No. 6, U.S. Dept. H.EW., Public Health Service Publication No. 947-6, May, 1966.

This publication lists direct costs of illnesses as expenditures for prevention, treatment, detection, rehabilitation, research, training and capital investment in medical facilities. The indirect costs include loss of output to the economy due to morbidity and mortality. Estimating procedures for both types of costs are summarized in this book.

(9) Acute Conditions; Incidence and Associated Disability, United States-July 1969-June 1970, D.H.E.W. Publication No. (HSM) 73-1503, National Center for Health Statistics, Rockville, Md., August, 1972.

APPENDIX C

Specific Pollutants

The following material presents a partial listing of what are considered to be the damaging pollutants. An accurate assessment and assignment of priorities is, of course, impossible without a detailed assessment of the damage potential of each individual pollutant. The following list of pollutants must, therefore, be interpreted as rather subjective and includes only some of the pollutants listed in Appendix A. Also included is the potential damage resulting from these pollutants, their most common source and the treatment required for their removal.

Exhibit C-1. Specific Pollutants

I. BOD, DO, and Coliform

II. Inorganic Phosphate (especially where lakes and reservoirs are being considered)

III. Inorganic Nitrogen

IV. Total Dissolved Solids

V. Turbidity, pH

VI. Temperature

VII. Pesticides and Toxic Substances

I. Dissolved Oxygen, Biochemical Oxygen Demand, and Coliform Count:

(A) Sources

The most generally accepted single criterion of pollution is the dissolved oxygen (DO) content of the stream. Under favorable nonpolluted conditions, this may approach the saturation value, or may even exceed saturation because of photosynthesis or oxygen generation in the stream.

The DO saturation value is low; it depends on temperature, and is only 14 mg/liter at the freezing point, less at usual stream temperatures. This implies that the reserve of available DO, to take care of bio-oxidation of organic wastes, is not great and is easily depleted. Organic wastes are generally characterized in terms of their biochemical oxygen demand (BOD); BOD is a measure of the oxygen consumed during biological oxidation. If large quantities of organic wastes are discharged into a stream, the dissolved oxygen in the stream may be rapidly depleted. These organic wastes occur in large quantities in industrial and municipal waste waters.

Coliform organisms are present in large quantities in the feces and urine of warmblooded animals. They are present in water because of discharges of inadequately treated sewage and because they reproduce when organic wastes are present in water.

Soil aeration and oxygen availability is also a factor deterring plant growth if water having high BOD values is used although no specific information is available.

(B) Damages

Total depletion of DO lends to nuisance conditions, including fish kills, bad odors and offensive appearances; even partial depletion may cause fish kills and render the stream unfit for its natural life forms.

Coliform counts in water samples, especially fecal coliform, provide a good indication of the level of potential water-borne pathogens capable of infecting man. Diseases can be transmitted from water to man in a number of ways (see section on Health).

(C) Treatment

Biological purification is widely used for treatment of waste water containing dissolved organic matter. There are two broad types of bio-oxidation equipment, trickling filters and activated sludge. Additional treatment can be obtained with carbon adsorption (tertiary treatment).

Chemical agents such as ozone, chlorine dioxide, and chlorine, which are capable of oxidative reaction with organic compound may cause disinfection by direct chemical degradation of fecal coliforms, virus and pathogenic bacteria.

II. Inorganic Phosphate

(A) Sources

Prior to the development of synthetic detergents, most of the inorganic phosphate was contributed by human waste as a result of metabolic processes. The average amount of phosphorus released per person in the United States is considered to be about 1.5 G/day.

Many synthetic detergents contain from 12 to 13 percent phosphorus or over 50 percent of polyphosphates. It has been estimated from sales of polyphosphates to the detergent industry that domestic sewage probably contains from two to three times as much inorganic phosphorus at the present time as it did before synthetic detergents became widely used.

Farm animals, poultry manures and agricultural runoffs also contribute some inorganic phosphate.

(B) Damage Effects

Phosphorus and nitrogen are both essential for the growth of algae. Limitation in the amounts of these elements is usually the factor that controls their rate of growth. Where both nitrogen and phosphorus are plentiful, algal blooms occur which may produce a variety of nuisance conditions. The critical level for phosphorus has been established as somewhere near 0.01 mg/l.

At concentration of complex phosphates of the order of 100 mg/l, difficulties with coagulation are experienced.

(C) Treatment

Inorganic phosphates can be removed by a number of methods. Among them, chemical coagulation is the most common way of removing inorganic phosphates. The function of chemical coagulation may be the removal of suspended solids by destabilization of colloids to increase the settling velocity of settleable material, or removal of soluble inorganic compounds, such as phosphorus, by chemical precipitation or adsorption on chemical floc. The inorganic coagulants commonly used in wastewater coagulation are aluminum salts such as aluminum sulfate (alnm), lime, or iron salts such as ferric chloride. Polymeric organic coagulants are also used either as primary coagulants or coagulant aids. More than 99 percent removal of phosphorus has been obtained and effluent qualities of 0.2 to 0.6 mg/l have been reported at South Lake Tahoe.

III. Inorganic Nitrogen

(A) Sources

Nitrogen compounds are released in human waste products. Urine contains the nitrogen resulting from the metaolic breakdown of proteins. Also the feces of animals contain appreciable amounts of unassimilated protein matter. The other sources of nitrogen come from agricultural runoff and industrial wastes.

(B) Damages

Nitrites and nitrates are dangerous to humans if taken in excess. It was reported first in 1945 that infants who drank water polluted with 140 mg per liter of nitrate-nitrogen and 0.4 mg per liter of nitrite-nitrogen showed signs of dangerous blood changes (methemoglobinemia). Experiments with minnows indicate that water containing 50 mg per liter of sodium nitrite is fatal to these fish in fourteen days. High concentrations of nitrates in waste water effluent act as a fertilizer and stimulate the growth of planktonic organisms and water-growing weeds. To a certain degree, this increase of planktonic growth with the accompanying development of fishfood organisms brings about an increase in fish production. As mentioned previously, where both nitrogen and phosphorus are plentiful, alga blooms occur which may produce a variety of nuisance conditions.

(C) Treatment

Three principal methods for removal of nitrogen from wastewater are ammonia stripping, selective ion exchange, and microbial denitrification. Of these, ammonia stripping is by far the cheapest, simplest, and easiest to control. Selective ion exchange is a reliable method, but a fairly complex one, and, at the present stage of development, appears to be rather costly. Microbial denitrification is inexpensive, but the process is difficult to sustain and control.

IV. Dissolved Solids

(A) Sources

Dissolved solids are mainly inorganic salts. The most important ones are chlorides, calcium and magnesium which are related to water hardness, and many other solutes. Inorganic salts arise from all sources--urban, industrial, agricultural, and natural; however, the largest portion comes from industrial sources, particularly crude petroleum production, the manufacture of soda ash and other chemicals. Unlike other types, these wastes are relatively stable and do not decompose, decay, or dissipate.

(B) Damages

Water with total dissolved solids (TDS) less than about 500 mg/liter are used by farmers without awareness of any salinity problem. Also without dilution from precipitation or an alternative supply, water with TDS of about 5000 mg/liter usually have little value for irrigation. Within these limits, the value of the water appears to decrease as the salinity increases. Where water is to be used regularly for the irrigation of relatively impervious soil, its value is limited if the TDS is in the range of 2000 mg/liter. Drinking water standards recommend that total dissolved solids not exceed 500 mg/l where other more suitable water supplies are available. The desired value is less than 200 mg/liter. High total dissolved solids are objectionable because of physiological effects and mineral taste. High concentrations of mineral salts, particularly sulfates and chlorides, are associated with corrosion damage in water systems and industrial facilities.

Scaling occurs when calcium or magnesium compounds in the water (water hardness) precipitate and adhere to boiler internal surfaces. These hardness compounds become less soluble as temperature increases, causing them to separate from solution. This scaling causes damage to heat transfer surface by decreasing the heat exchange capability. The result is overheating of tubes, followed by failure and equipment damage.

(C) Treatment

Hard waters are often softened by adding sufficient quantities of lime and soda ash to precipitate the calcium and magnesium as calcium carbonate and magnesium hydroxide. Ion exchange, veversis osmosis, electrodialysis, freezing, distillation and other desalination processes are also used for removing dissolved solids. These processes are relatively expensive.

V. Turbidity and pH

(A) Sources

The term turbid is applied to waters containing suspended matter that interferes with the passage of light through the water or in which visual depth is restricted. The turbidity may be caused by a wide variety of suspended materials, which range in size from colloidal to coarse dispersions, depending upon the degree of turbulence. As rivers descend from mountain areas onto the plains, they receive contributions of turbidity from farming and other operations that disturb the soil. Under flood conditions, great amounts of topsoil are washed to receiving streams. Much of this material is inorganic in nature but considerable amounts of organic matter are included. The domestic waste may add great quantities of organic and some inorganic materials that contribute turbidity. Certain industrial wastes may add large amounts of organic substances and other inorganic substances that produce turbidity. Street washings contribute much inorganic and some organic turbidity.

Most of the acid or alkali content comes from many industrial wastes.

(B) Damage

Any turbidity in the drinking water is automatically associated with increased filtration in industrial and municipal preuse treatment processes.

Filtration of water is rendered more difficult and costly when turbidity increases. The use of slow sand filters has become impractical in most areas because high turbidity shortens filter runs and increases cleaning costs. In turbid waters, most of the harmful organisms are exposed to the action of the disinfectant. However, in cases in which turbidity is caused by sewage solids, many of the pathogenic organisms may be encased in the particles and protected from the disinfectants. For this and aesthetic reasons the United States Public Health Service has placed a limit of five units of turbidity as the maximum amount allowable in public water supplies.

In addition to increased municipal and industrial costs turbidity further reduces the esthetic value of streams and lakes.

Either a high or a low pH may be damaging, causing fish kills and general sterility in natural streams, and inactivating the essential microorganisms in sewage treatment processes. Waste of low pH are corrosive to steel and concrete structures in waterways or sewage systems.

The lacrimal fluid of the human eye has a normal pH of approximately 7.4 and a very high buffering capacity, due primarily to the presence of buffering agents of the complex organic type. As is true of many organic buffering agents, those of the lacrimal fluid are able to maintain the pH within a very narrow range until their buffering capacity is exhausted. When the lacrimal fluid, through exhaustion of its buffering capacity, is unable to adjust the immediate contact layers of the fluid to a pH of 7.4, eye irritation results. A deviation of no more than 0.1 unit from the normal pH of the eye may result in discomfort. Appreciable deviation will cause severe pain.

(C) Treatment

Inorganic and organic colloidal suspensions in water can be removed by chemical coagulation. The coagulation process, as practiced in waste water treatment, involved destabilization of the colloidal suspension follwed by flocculation to generate large particles which can subsequently be removed either by sedimentation, flotation, or filtration.

To eliminate the extremes of pH in wastewaters usual chemical neutralization is applied.

VI. Temperature

(A) Sources

While the contribution of heat from solar radiation is important, the primary interest of the regulatory agencies is with heat added to the environment from industrial processes. Although the most significant source of thermal pollution is steam-electrical generating activities, it should be noted that the process industries which withdraw water for cooling purposes also contribute waste heat to the environment. The amount of fresh water required for cooling condensers is estimated to increase from the 1955 usage of 60 billion gallons a day to 200 billion gallons -- one-sixth of the fresh water in the United States--by 1988. This heat can often be discharged either to the atmosphere or to water.

(B) Benefits and Damages

Temperature is one of the single most important factors controlling the distribution and survival of aquatic organisms. Temperature increases affect fish directly by changing physiological and behavioral processes, and indirectly by changing some aspect of the environment on which fish depend. Mayer (1914) suggested that high temperatures produced death in cold blooded animals by causing asphyxiation, the oxygen being insufficient to sustain the increased metabolic activity. Sudden changes in stream temperature, such as occur because of a plant shut down in winter can also cause fish kills and other damages.

Some heating of streams and rivers can be beneficial. Fish grow faster at warmer temperatures. Melting of ice on rivers can sometimes be desirable. Excessively high temperature may lessen the pleasure of some water contact sports, as well as be damaging to biota. It has been determined that a person swimming expends energy at the rate of approximately 500 calories per hour. This energy must be dissipated to the environment to avoid a rise in the deep body temperature. When conduction is the principal means of heat transfer from the body and exposure to the environmental conditions is prolonged, 90° F is the approximate limit for persons expending minimal energy. High water temperature also reduces the cooling efficiency of water used as industrial coolants.

(C) Treatment

Thermal pollution of streams can be prevented by discharging the waste heat elsewhere. Small man-made lakes can sometimes be used where water cooling is economically desirable.

VII. Pesticides

(A) Sources

Pesticides are materials used to prevent, destroy, repel, or otherwise control objectionable insects, rodents, plants, weeds, or other undesirable forms of life. Pesticides may gain access to ground and surface water supplies through percolation and runoff from treated areas.

(B) Damages

Some pesticides are toxic to fish and other aquatic life at only a small fraction of a mg/l. Laboratory tests show that many coastal fisheries are especially sensitive to the toxic effects of low levels of pesticides. Oysters, for example, will exist in the presence of DDT at levels as high as 0.1 mg/l in the environment. But at levels 1000 times less (0.1 mg/l) oyster growth or production would be only 20 percent of normal, shrimp population would suffer a 20-percent mortality, and menhaden would suffer a disastrous mortality. They also tend to concentrate in aquatic plants and animals to values several thousand times that occurring in the water in which they live. Also, some pesticides are quite resistant to biological degradation and persist in soils and water for long periods of time.

(C) Treatment

The presence of pesticides is difficult to handle. The best way is to avoid them rather than to remove them.

APPENDIX D

Critical Levels and Damage Thresholds

Many aspects of water quality management must proceed by disaggregating the problem into manageable proportions. When assessing the costs of pollution one must consider a variety of individual water quality constituents. For this reason there is value in presenting a variety of critical levels and damage thresholds by beneficial uses. The following tables present a number of established water quality guidelines and standards that have been adopted.

Exhibit D-1. Guide for Evaluating the Quality of Water Used for Contact Recreation

Quality factor	Limiting Concentration
Fecal Coliform, MPN per 100 ml	200
Range of pH	6.5 - 8.3
Temperature, maximum (°C)	30
Clarity	A secchi disc is visible at a minimum depth of 4 feet
Flotable oil and grease, mg/liter	5
Emulsified oil and grease, mg/liter	20
Suspended solids, mg/liter	100
Threshold odor number	256

Source: Report of the Committee on Water Quality Criteria, Federal Water Pollution Control Administration, U. S. Department of the Interior, p. 4.

Exhibit D-2. Guide for Evaluating the Quality of Water Used for General Recreation (Boating and Esthetic)

Quality factor	Limiting Concentration	
Fecal coliform, MPN per 100 ml	1,000	
Range of pH	6.0 - 9.0	
Total dissolved solids (TDS), mg/liter	1,500	
Dissolved oxygen, minimum mg/liter	5	
Carbon dioxide, mg/liter	25	
Turbidity, JN	25	
Phosphorus, mg/liter	100	(flowing stream)
	50	(lakes or reservoirs)
Flotable oil and grease, mg/liter	10	
Emulsified oil and grease, mg/liter	50	
Threshold odor number	256	

Exhibit D-3. Guide for Evaluating the Quality of Water Used for Marine and Estuarine

Quality Factor	Limiting Concentration
Salinity change, maximu, %	± 10
Range of pH	6.7 - 8.5
Temperature change, maximum	1.5 - summer 4 - fall, spring and winter
Dissolved oxygen, mg/liter	5

Exhibit D-4

DRINKING WATER STANDARDS

Substance	Preferable Limits	Rejection Limits
Coliforms, MPN	--	1
Fecal coliforms, MPN	--	1
Arsenic, mg/l	0.01	0.05
Barium "	--	1.0
Boron "	--	0.01
Cadmium "	--	0.01
Chloride "	250	--
Chromium (hexavalent)	--	0.05
Copper "	1.0	--
Iron "	0.3	--
Manganese "	0.05	--
Lead "	--	0.05
Nitrate "	45	--
Selenium "	--	0.01
Silver "	--	0.05
Sulfate "	250	--
Total Dissolved Solids	500	--
Zinc "	5	--
Cyanide "	0.01	0.2
Phenols "	0.001	--

	USPHS	AWWA Goals
Turbidity, units	5	<0.1
Color, units	15	<3
Odor (threshold odor number)	3	No odor
Taste	--	None objectionable

Exhibit D-5

Summary of Specific Quality Characteristics of Surface Waters That Have Been Used as Sources for Industrial Water Supplies

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.]

Characteristic	Boiler makeup water		Cooling water				Process water							
			Fresh		Brackish [1]									
	Industrial 0 to 1,500 psig	Utility 700 to 5,000 psig	Once through	Makeup recycle	Once through	makeup recycle	Textile industry, SIC-22	Lumber industry, SIC-24	Pulp and paper industry, SIC-26	Chemical industry, SIC-28	Petroleum industry, SIC-29	Prim. metals industry, SIC-33	Food and kindred products, SIC-20	Leather industry, SIC-31
Silica (SiO_2)	150	150	50	150	25	25	-----	-----	50	-----	50	-----	For the above 2 categories the quality of raw surface supply should be that prescribed by the NTA Subcommittee on Water Quality Requirements for Public Water Supplies.	
Aluminum (Al)	3	3	3	3	-----	-----	-----	-----	-----	-----	-----	-----		
Iron (Fe)	80	80	14	80	1.0	1.0	0.3	-----	2.6	5	15	-----		
Manganese (Mn)	10	10	2.5	10	0.02	0.02	1.0	-----	-----	2	-----	-----		
Copper (Cu)	-----	-----	-----	-----	-----	-----	0.5	-----	-----	-----	-----	-----		
Calcium (Ca)	-----	-----	500	500	1,200	1,200	-----	-----	-----	200	220	-----		
Magnesium (Mg)	-----	-----	-----	-----	-----	-----	-----	-----	-----	100	85	-----		
Sodium and potassium (Na+K).	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	230	-----		
Ammonia (NH_3)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----		
Bicarbonate (HCO_3)	600	600	600	600	180	180	-----	-----	-----	600	480	-----		
Sulfate (SO_4)	1,400	1,400	680	680	2,700	2,700	-----	-----	-----	850	570	-----		
Chloride (Cl)	19,000	19,000	600	500	22,000	22,000	-----	-----	200 [2]	500	1,600	500		
Fluoride (F)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.2	-----		
Nitrate (NO_3)	-----	-----	30	30	-----	-----	-----	-----	-----	-----	8	-----		
Phosphate (PO_4)	-----	50	4	4	5	5	-----	-----	-----	-----	-----	-----		
Dissolved solids	35,000	35,000	1,000	1,000	35,000	35,000	150	-----	1,080	2,500	3,500	1,500		
Suspended solids	15,000	15,000	5,000	15,000	250	250	1,000	(3)	-----	10,000	5,000	3,000		
Hardness ($CaCO_3$)	5,000	5,000	850	850	7,000	7,000	120	-----	475	1,000	900	1,000		
Alkalinity ($CaCO_3$)	500	500	500	500	150	150	-----	-----	-----	500	-----	200		
Acidity ($CaCO_3$)	1,000	1,000	0	200	0	0	-----	-----	-----	-----	-----	75		
pH, units	-----	-----	5.0–8.9	3.5–9.1	5.0–8.4	5.0–8.4	6.0–8.0	5–9	4.6–9.4	5.5–9.0	6.0–9.0	3–9		
Color, units	1,200	1,200	-----	1,200	-----	-----	-----	-----	360	500	25	-----		
Organics:														
Methylene blue active substances.	2 [4]	10	1.3	1.3	-----	1.3	-----	-----	-----	-----	-----	-----		
Carbon tetrachloride extract.	100	100	(5)	100	(5)	100	-----	-----	-----	-----	-----	30		
Chemical oxygen demand (O_2).	100	500	-----	100	-----	200	-----	-----	-----	-----	-----	-----		
Hydrogen sulfide (H_2S).	-----	-----	-----	-----	4	4	-----	-----	-----	-----	-----	-----		
Temperature, F	120	120	100	120	100	120	-----	-----	95 [6]	-----	-----	100		

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[1] Water containing in excess of 1,000 mg/l dissolved solids.
[2] May be ≤ 1,000 for mechanical pulping operations.
[3] No large particles ≤ 3 mm diameter.
[4] 1 mg/l for pressures up to 700 psig.
[5] No floating oil.
[6] Applies to bleached chemical pulp and paper only.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1) or APHA Standard methods for the examination of water and waste-water (5).

Report of the Committee on Water Quality Criteria, Federal Water Pollution Control Administration, U. S. Department of the Interior, p. 20.

Exhibit D-6. Guides for evaluating recreational waters

Determination	Water contact		Boating and aesthetic	
	Noticeable threshold	Limiting threshold	Noticeable threshold	Limiting threshold
Coliforms, MPN per 100 ml	1000*	†		
Visible solids of sewage origin	None	None	None	None
ABS (detergent), mg/liter	1*	2	1*	5
Suspended solids, mg/liter	20*	100	20*	100
Flotable oil and grease, mg/liter	0	5	0	10
Emulsified oil and grease, mg/liter	10*	20	20*	50
Turbidity, silica scale units	10*	50	20*	‡
Color, standard cobalt scale units	15*	100	15*	100
Threshold odor number	32*	256	32*	256
Range of pH	6.5-9.0	6.0-10.0	6.5-9.0	6.0-10.0
Temperature, maximum °C	30	50	30	50
Transparency, Secchi disk, ft	. . .	. . .	20*	‡

*Value not to be exceeded in more than 20 percent of 20 consecutive samples, nor in any 3 consecutive samples.

†No limiting concentration can be specified in the basis of epidemiological evidence, provided no fecal pollution is evident. (Note: Noticeable threshold represents the level at which people begin to notice and perhaps to complain. Limiting threshold is the level at which recreational use of water is prohibited or seriously impaired.

‡No concentration likely to be found in surface waters would impede use.

Source: California State Water Control Board, 1963

Exhibit D-7. Guides for evaluating the quality of water used by livestock

Quality factor	Threshold concentration*	Limiting concentration†
Total dissolved solids (TDS), mg/liter	2500	5000
Cadmium, mg/liter	5	
Calcium, mg/liter	500	1000
Magnesium, mg/liter	250	500‡
Sodium, mg/liter	1000	2000‡
Arsenic, mg/liter	1	
Bicarbonate, mg/liter	500	500
Chloride, mg/liter	1500	3000
Fluoride, mg/liter	1	6
Nitrate, mg/liter	200	400
Nitrite, mg/liter	None	None
Sulfate, mg/liter	500	1000‡
Range of pH	6.0-8.5	5.6-9.0

*Threshold values represent concentrations at which poultry or sensitive animals might show slight effects from prolonged use of such water. Lower concentrations are of little or no concern.

†Limiting concentrations based on interim criteria, South Africa. Animals in lactation or production might show definite adverse reactions.

‡Total magnesium compounds plus sodium sulfate should not exceed 50 percent of the total dissolved solids.

Source: California State Water Quality Control Board, 1963

Exhibit D-8. Quality standards for water used for livestock

	Threshold Salinity Concentration, ppm.
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle, dairy	7,150
Cattle, beef	10,000
Adult dry sheep	12,900

Source: Jour. of Agriculture of Western Australia, 1950

Exhibit D-9. Limits of Boron in irrigation water

A. Permissible Limits
[Boron in parts per million]

Class of water	Crop Group		
	Sensitive	Semitolerant	Tolerant
Excellent	< 0.33	< 0.67	< 1.00
Good	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
Permissible	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	> 1.25	> 2.50	> 3.75

B. Crop Groups of Boron Tolerance
[In each group, the plants first named are considered as being more tolerant; the last named, more sensitive.]

Sensitive	Semitolerant	Tolerant
Pecan	Sunflower (native)	Athel *(Tamarix aphylla)*
Walnut (Black; and Persian, or English)	Potato	Asparagus
Jerusalem-artichoke	Cotton (Acala and Pima)	Palm *(Phoenix canariensis)*
Navy bean	Tomato	Date palm *(P. dactylifera)*
American elm	Sweetpea	Sugar beet
Plum	Radish	Mangel
Pear	Field pea	Garden beet
Apple	Ragged Robin rose	Alfalfa
Grape (Sultanina and Malaga)	Olive	Gladiolus
Kadota fig	Barley	Broadbean
Persimmon	Wheat	Onion
Cherry	Corn	Turnip
Peach	Milo	Cabbage
Apricot	Oat	Lettuce
Thornless blackberry	Zinnia	Carrot
Orange	Pumpkin	
Avocado	Bell pepper	
Grapefruit	Sweet potato	
Lemon	Lima bean	

Source: U. S. Department of Agriculture

Exhibit D-10. Guides for evaluating the quality of water used for irrigation

[MPN is most probable number. Sodium adsorption ratio is defined by the formula $SAR=Na/\sqrt{(Ca+Mg)/2}$ where the concentrations are expressed in milliequivalents per liter. Residual sodium carbonate is the sum of the equivalents of normal carbonate and bicarbonate minus the sum of the equivalents of calcium and magnesium.]

Quality factor	Threshold concentration*	Limiting concentration†
Coliform organisms, MPN per 100 ml	1000‡	§
Total dissolved solids (TDS), mg/liter	500‡	1500‡
Electrical conductivity, µmhos/cm	750‡	2250‡
Range of pH	7.0-8.5	6.0-9.0
Sodium adsorption ratio (SAR)	6.0‡	15
Residual sodium carbonate (RSC), meq	1.25‡	2.5
Arsenic, mg/liter	1.0	5.0
Boron, mg/liter	0.5‡	2.0
Chloride, mg/liter	100‡	350
Sulfate, mg/liter	200‡	1000
Copper, mg/liter	0.1‡	1.0

*Threshold values at which irrigator might become concerned about water quality and might consider using additional water for leaching. Below these values, water should be satisfactory for almost all crops and almost any arable soil.

†Limiting values at which the yield of high-value crops might be reduced drastically, or at which an irrigator might be forced to less valuable crops.

‡Values not to be exceeded more than 20 percent of any 20 consecutive samples, nor in any 3 consecutive samples. The frequency of sampling should be specified.

§Aside from fruits and vegetables which are likely to be eaten raw, no limits can be specified. For such crops, the threshold concentration would be limiting.

Source: Calif. State Water Quality Control Board, 1963

Exhibit D-11. Guides for evaluating the quality of water for aquatic life

Determination	Threshold concentration*	
	Freshwater	Saltwater
Total dissolved solids (TDS), mg/liter	2000†	
Electrical conductivity, µmhos/cm @ 25°C	3000†	
Temperature, maximum °C	34	34
Maximum for salmonoid fish	23	23
Range of pH	6.5-8.5	6.5-9.0
Dissolved oxygen (D.O.), minimum mg/liter	5.0‡	5.0‡
Flotable oil and grease, mg/liter	0	0†
Emulsified oil and grease, mg/liter	10†	10†
Detergent, ABS, mg/liter	2.0	2.0
Ammonia (free), mg/liter	0.5†	
Arsenic, mg/liter	1.0†	1.0†
Barium, mg/liter	5.0†	
Cadmium, mg/liter	0.01†	
Carbon dioxide (free), mg/liter	1.0	
Chlorine (free), mg/liter	0.02	
Chromium, hexavalent, mg/liter	0.05†	0.05†
Copper, mg/liter	0.02†	0.02†
Cyanide, mg/liter	0.02†	0.02†
Fluoride, mg/liter	1.5†	1.5†
Lead, mg/liter	0.1†	0.1†
Mercury, mg/liter	0.01	0.01
Nickel, mg/liter	0.05†	
Phenolic compounds, as phenol, mg/liter	1.0	
Silver, mg/liter	0.01	0.01
Sulfide, dissolved, mg/liter	0.5†	0.5†
Zinc, mg/liter	0.1	

*Threshold concentration is value that normally might not be deleterious to fish life. Waters that do not exceed these values should be suitable habitats for mixed fauna and flora.

†Values not to be exceeded more than 20 percent of any 20 consecutive samples, nor in any 3 consecutive samples. Other values should never be exceeded. Frequency of sampling should be specified.

‡Dissolved oxygen concentrations should not fall below 5.0 mg/liter more than 20 percent of the time and never below 2.0 mg/liter. (Note: Recent data indicate also that rate of change of oxygen tension is an important factor, and that diurnal changes in D.O. may, in sewage-polluted water, render the value of 5.0 of questionable merit.)

Source: Calif. State Water Quality Control Board, 1963

Exhibit D-12. Observed lethal concentration of selected chemicals in aquatic environments

Chemical	Organism tested	Lethal concentration, mg/liter	Exposure time,hr
ABS (100 percent)	Fathead minnow	3.5-4.5	96
ABS (100 percent)	Bluegills	4.2-4.4	96
Household syndets	Fathead minnow	39-61	96
Alkyl sulfate	Fathead minnow	5.1-5.9	96
LAS (C12)	Bluegill fingerlings	3	96
LAS (C14)	Bluegill fingerlings	0.6	96
Acetic acid	Goldfish	423	20
Alum	Goldfish	100	12-96
Ammonia	Goldfish	2-2.5 NH_3	24-96
Ammonia	Perch, roach, rainbow trout	3N	2-20
Sodium arsenite	Minnow	17.8 As	36
Sodium arsenate	Minnow	234 As	15
Barium chloride	Goldfish	5000	12-17
Barium chloride	Salmon	158	. . .
Cadmium chloride	Goldfish	0.017	9-18
Cadmium nitrate	Goldfish	0.3 Cd	190
CO_2	Various species	100-200	. . .
CO	Various species	1 5	1-10
Chloramine	Brown trout fry	0.06	. . .
Chlorine	Rainbow trout	0.03-0.08	. . .
Chromic acid	Goldfish	200	60-84
Copper sulfate	Stickleback	0.03 Cu	160
Copper nitrate	Stickleback	0.02 Cu	192
Cyanogen chloride	Goldfish	1	6-48
H_2S	Goldfish	10	96
HCl	Stickleback	pH 4.8	240
HCl	Goldfish	pH 4.0	4-6
Lead nitrate	Minnow, stickleback, brown trout	0.33 Pb	. . .
Mercuric chloride	Stickleback	0.01Hg	204
Nickel nitrate	Stickleback	1 Ni	156
Nitric acid	Minnow	pH 5.0	. . .
Oxygen	Rainbow trout	3 cc/liter	. . .
Phenol	Rainbow trout	6	3
Phenol	Perch	9	1
Potassium chromate	Rainbow trout	75	60
Potassium cyanide	Rainbow trout	0.13 Cn	2
Sodium cyanide	Stickleback	1.04 Cn	2
Silver nitrate	Stickleback	70 K	154
Sodium fluoride	Goldfish	1000	60-102
Sodium sulfide	Brown trout	15	. . .
Zinc sulfate	Stickleback	0.3 Zn	120
Zinc sulfate	Rainbow trout	0.5	64
Pesticides			
1. Chlorinated hydrocarbons			
A Aldrin	Goldfish	0.028	96
DDT	Goldfish	0.027	96
DDT	Rainbow trout	0.5-0.32	24-36
DDT	Salmon	0.08	36
DDT	Brook trout	0.032	36
DDT	Minnow, guppy	0.75 ppb	29
DDT	Stoneflies (species)	0.32-1.8	96
BHC	Goldfish	2.3	96
BHC	Rainbow trout	3	96
Chlordane	Goldfish	0.082	96
Chlordane	Rainbow trout	0.5	24
Dieldrin	Goldfish	0.037	96
Dieldrin	Bluegill	0.008	96
Dieldrin	Rainbow trout	0.05	24

Exhibit D-12 (continued)

Chemical	Organism tested	Lethal concentration, mg/liter	Exposure time, hr
Endrin	Goldfish	0.0019	96
Endrin	Carp	0.14	48
Endrin	Fathead minnow	0.001	96
Endrin	Various species	0.03-0.05 ppb	. . .
Endrin	Stoneflies (species)	0.32-2.4 ppb	96
Heptachlor	Rainbow trout	0.25	24
Heptachlor	Goldfish	0.23	96
Heptachlor	Bluegill	0.019	96
Heptachlor	Redear sunfish	0.017	96
Methoxychlor	Rainbow trout	0.05	24
Methoxychlor	Goldfish	0.056	96
Toxaphene	Rainbow trout	0.05	24
Toxaphene	Goldfish	0.0056	96
Toxaphene	Carp	0.1	. . .
Toxaphene	Goldfish	0.2	24
Toxaphene	Goldfish	0.04	170
Toxaphene	Minnows	0.2	24
2. Organic phosphates			
Chlorothion	Fathead minnow	3.2	96
Dipterex	Fathead minnow	180	96
EPN	Fathead minnow	0.2	96
Guthion	Fathead minnow	0.093	96
Guthion	Bluegill	0.005	96
Malathion	Fathead minnow	12.5	96
Parathion	Fathead minnow	1.4-2.7	96
TEPP	Fathead minnow	1.7	96
3. Herbicides			
Weedex	Young roach and trench	40-80	1 month
Weeda Zol		15-30	1 month
Weeda Zol T.L.		20-40	1 month
Simazine (no plants present)	Minnow	0.5	< 3 days
Atrazine (A361) (plants present)	Minnow	5.0	24
Atrazine in Gesaprime	Minnow	3.75	24
4. Bactericides			
Algibiol	Minnow	20	24
Soricide tetraminol	Minnow	8	48

Source: McGauhey, Engineering Management of Water Quality, McGraw-Hill, copyright 1968

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